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The status of renewable energy in the GCC countries

W.E. Alnaser [a,*], N.W. Alnaser [b]

[a] College of Science, University of Bahrain, PO Box 32038, Bahrain
[b] College of Applied Studies, University of Bahrain, PO Box 32038, Bahrain

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A B S T R A C T

Due to the vast growth of development in the infrastructure and investment in energy, the electricity consumption in the GCC countries had increased at a fast rate; 12.4% from 2005 to 2009 (3.15%, annually). This rate is much larger than the world average, which is 2.2% for the same period, or USA (0.5%). In 2005, the average Watt per person in the GCC countries was 1149 which is much higher than the world average (297 W per person) or the European Union (700 W/person) – but less than USA (1460 W/person). The GCC countries need to increase its electrical capacity by 60,000 MW, which represents 80% of the current installed capacity, to meet demand in 2015. This means that there is a need to build 50 more gas fired power generator plant turbine (each rated 1400 MW).

The GCC countries have realized that depending on gas will not be the solution due to shortage of resource or environmental impact, particularly the GHG emissions. Therefore, they thought back of using renewable energy resources – after lifting it over in 1990s. They also thought of diversity in electricity production where nuclear energy comes to the picture. The power capacity in GCC countries is at around 75,000 MW, a projected 9.5% growth in annual demand will require more electricity and energy projects; expected to invest USD 200 billion to 250 billion in between 14 and 20 energy projects by 2020.

The paper lists the major renewable energy projects (mainly solar and wind) in each of the six GCC countries. The total capacity of these projects exceeds 600 MW. Among these projects is the establishment of the first zero emission house (Green house) in the middle east (7 kW solar, wind and fuel cell) constructed in Bapco residence town (Awali) in Bahrain and therefore, been highlighted more in this paper. Moreover, nearly all GCC countries are planning to construct PV plants with large capacity. Also, several projects in Building Integrated Photovoltaic and Building Integrated Wind Turbines are established in GCC countries.

The projects made in the GCC countries allow researchers and investors to size the cost of kWh from thermal, PV and wind energy more precisely. For example, it was found that the cost of kWh from large grid connected solar thermal plant (20 MW) – with cost of USD 72.5 million and energy – is US ¢ 12/kWh (assuming a life time of 40 years and a discount rate of 4%) while, the cost issue of kWh from PV Electricity (in the GCC countries) is ranging from US ¢ 27 (for ground mount) to US ¢ 35 (for roof mount) as it was deduced from two actually installed project PV in UAE – a GCC country member. Meanwhile, the cost of 1 kWh from wind electricity in the GCC countries may be from US ¢10 (large turbine ≈2 MW at 80 m height with good wind speed) to US ¢ 15 (for large turbine ≈2 MW at 80 m height with modest wind speed) while the cost of kWh from grid connected Wind farm plant (20 MW) – with a cost of USD 38.6 million and energy – is US ¢ 6.7/kWh to US ¢ 8.8/kWh, depending on the location of wind farm. This makes it very challengeable for investor, government (Feed-in-Tariff) and citizens because each citizen in GCC countries pays only (US cent 1 for each kWh, for consumption less than 3000 kWh, or even nothing for citizens-like in Qatar).

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* Corresponding author.
E-mail address: alnaserw@gmail.com (W.E. Alnaser).

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1. Introduction

The potential for solar power generation in the Gulf Cooperation Council (GCC) countries is enormous. Every year, each km^2 of land receives an amount of solar energy (nearly 500–600 W/m^2) equivalent to 1.5 million barrels of crude oil, i.e. each m^2 receive 1.5 barrel (≈240 L) of solar energy equivalent. Unfortunately, solar power was not featured in these countries' energy mix. Fortunately, the increasing environmental pressure from international countries on the oil producing nations forced GCC countries to examine its energy strategy and improve its green credentials. Furthermore, with the high price of oil, countries are considering the merits of increasing export volumes and decreasing domestic use.

The need for water in these countries has leaded their policy makers in GCC countries to use renewable energy for water desalination especially their ground water is brackish and their sea water is of high. The technologies and costs of desalinating sea water consume much more energy than brackish water. According to Lenntech water treatment solutions, depending on the site of the plant, the total costs of desalinated sea water vary between US$ 0.5 and US$ 0.8. In GCC countries, the costs of producing desalinating water ranges from US$ 0.45 (with subsidies) to US$ 1 per m^3, knowing that 41% of the desalination cost is in electricity and 26% for consumables.

According to International Energy Outlook (IEO) 2010 [1] the world market energy consumption increases by 49%, or 1.4% per year, from 2007 to 2035 in the Reference case (Fig. 1 and Table 1). The total energy demand in non-OECD countries (among them the GCC countries) had increased by 84%, compared with an increase of 14% in OECD countries.

The total world energy use rises from 495 quadrillion British thermal units (Btu) in 2007 to 590 quadrillion Btu in 2020 and 739 quadrillion Btu in 2035 (Fig. 2). The global economic recession that began in 2008 and continued into 2009 has had a profound impact on world energy demand in the near term. Total world marketed energy consumption contracted by 1.2% in 2008 and by an estimated 2.2% in 2009, as manufacturing and consumer demand for goods and services declined. Although the recession appears to have ended, the pace of recovery has been uneven so far, with China and India leading and Japan and the European Union member countries lagging [1].

The *IEO2010* Reference case projects increased world consumption of marketed energy from all fuel sources over the 2007–2035 projection periods (Fig. 3). Fossil fuels are expected to continue supplying much of the energy used worldwide. Although liquid fuels remain the largest source of energy, the liquids share of world marketed energy consumption falls from 35% in 2007 to 30% in 2035,

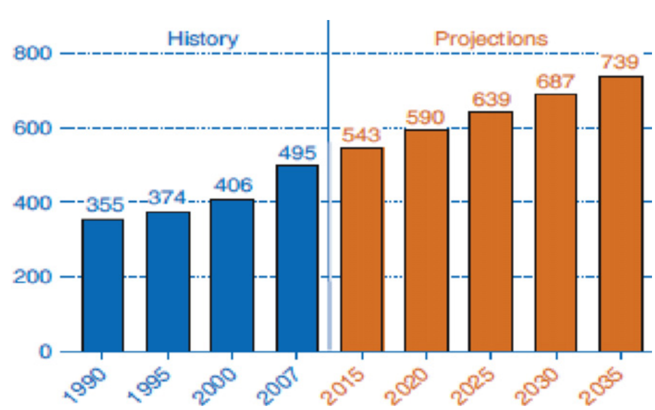


Fig. 1. World marketed energy consumption, in quadrillion Btu, for the period from 1990 to 2035.

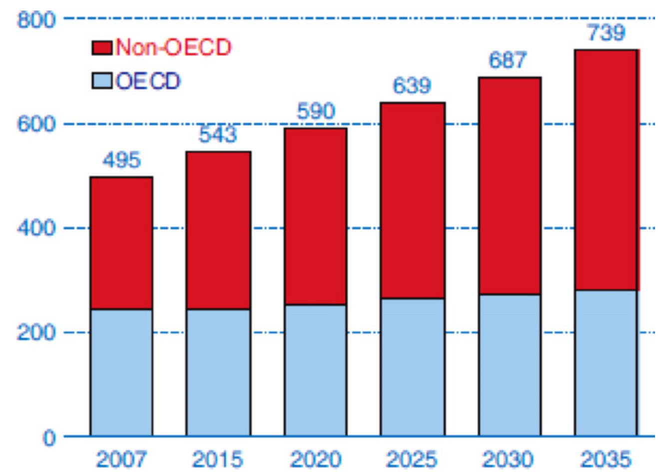


Fig. 2. World market energy consumption 2006–2035 in quadrillion Btu [1].

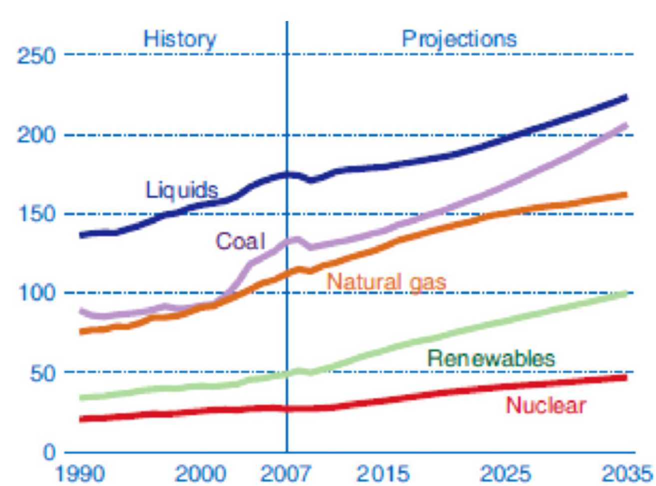


Fig. 3. World Market energy in quadrillion Btu, use by fuel type, 1990–2030 [1].

Table 1
World marketed energy consumption by country grouping, in quadrillion Btu, for the period from 1990 to 2035. GCC countries are among Middle East.

Region	2007	2015	2020	2025	2030	2035	Average annual percent change, 2007–2035
OECD	245.7	246.0	254.2	263.2	271.4	280.7	0.5
North America	123.7	124.3	129.4	134.9	140.2	146.3	0.6
Europe	82.3	82.0	83.0	85.0	86.5	88.2	0.2
Asia	39.7	39.7	41.8	43.3	44.8	46.3	0.5
Non-OECD	249.5	297.5	336.3	375.5	415.2	458.0	2.2
Europe and Eurasia	51.5	52.4	54.2	56.2	57.8	60.2	0.6
Asia	127.1	159.3	187.8	217.0	246.9	277.3	2.8
Middle East	25.1	32.9	36.5	39.1	41.8	45.7	2.2
Africa	17.8	20.8	22.5	24.6	26.5	29.0	1.8
Central and South America	28.0	32.1	35.5	38.7	42.2	45.7	1.8
Total world	495.2	543.5	590.5	638.7	686.5	738.7	1.4

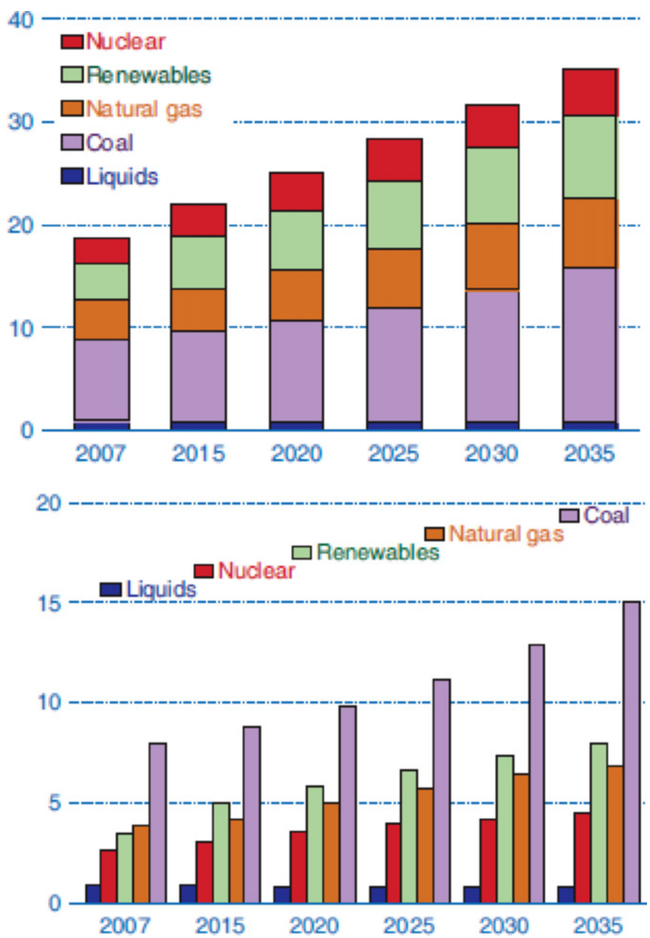


Fig. 4. World net electricity generation by fuel in trillion kWh for the period from 2007 to 2030 [1].

as projected high world oil prices lead many energy users to switch away from liquid fuels when feasible.

In IEO report [1], the world net electricity generation increases by 87% in the Reference case, from 18.8 trillion kWh in 2007 to 25.0 trillion kWh in 2020 and 35.2 trillion kWh in 2035. Although the recession slowed the growth in electricity demand in 2008 and 2009, growth returns to pre-recession rates by 2015 in the Reference case. In general, in OECD countries, where electricity markets are well established and consumption patterns are matured, the growth of electricity demand is slower than in non-OECD countries (GCC countries), where a large amount of potential demand remains unmet. In the Reference case, total net electricity generation in non-OECD countries increases by 3.3% per year on average, as compared with 1.1% per year in OECD nations.

Table 2
World oil reserves, in billion barrels, by country as of January 2010 [2]; 1 barrel of oil = 159 L).

Country	Oil reserves	Percent of world total
Saudi Arabia	259.9	19.20
Canada	175.2	12.94
Iran	137.6	10.16
Iraq	115.0	8.50
Kuwait	101.5	7.50
Venezuela	99.4	7.34
United Arab Emirates	97.8	7.22
Russia	60.0	4.43
Libya	44.3	3.27
Nigeria	37.2	2.75
Kazakhstan	30.0	2.22
Qatar	25.4	1.88
China	20.4	1.51
United States	19.2	1.42
Brazil	12.8	0.95
Algeria	12.2	0.90
Mexico	10.4	0.77
Angola	9.5	0.70
Azerbaijan	7.0	0.52
Norway	6.7	0.49
Rest of world	72.2	5.33
World total	1,353.7	100.00

Source: Oil & Gas Journal.

Table 3
The world natural gas reserves in different countries, in trillion ft^3, as of January 2010 [3]. The GCC countries sell natural gas for its local energy and industrial sector for USD 1.25 per 1 million Btu or per 1000 ft^3 (1 ft^3 = 1027 Btu) where the average international price is nearly USD 4.737 per million Btu. Note that 1 ton of natural gas ≈ 45 million Btu.

Country	Reserves (trillion ft^3)	Percent of world total
World	6609	100.0
Top 20 countries	6003	90.8
Russia	1680	25.4
Iran	1046	15.8
Qatar	899	13.6
Turkmenistan	265	4.0
Saudi Arabia	263	4.0
United Satates	245	3.7
United Arab Emirates	210	3.2
Nigeria	185	2.8
Venezuela	176	2.7
Algeria	159	2.4
Iraq	112	1.7
Australia	110	1.7
China	107	1.6
Indonesia	106	1.6
Kazakhstan	85	1.3
Malaysia	83	1.3
Norway	82	1.2
Uzbekistan	65	1.0
Kuwait	63	1.0
Canada	62	0.9
Rest of world	606	9.2

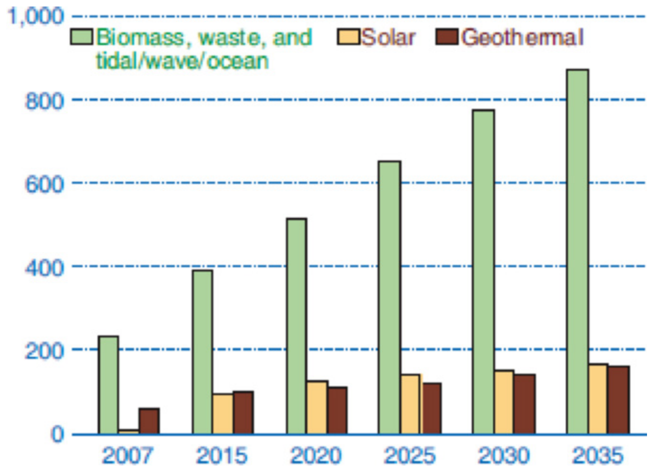


Fig. 5. World renewable electricity generation by energy sources, excluding wind and hydro power, in billion kWh, for the period from 2007 to 2035.

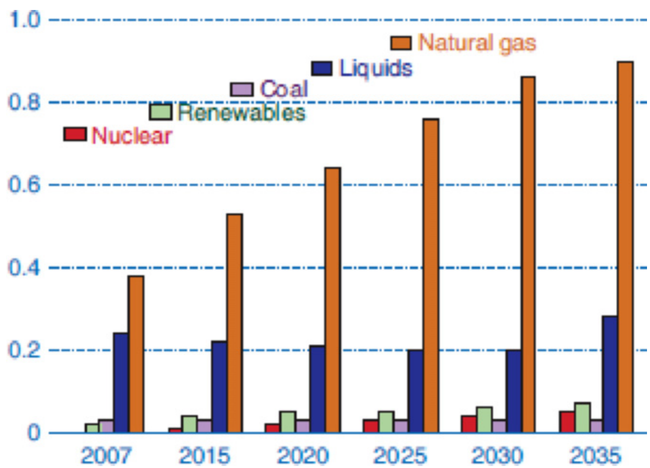


Fig. 6. Net electricity generation in the Middle East by fuel, 2007–2035 in trillion kWh [1].

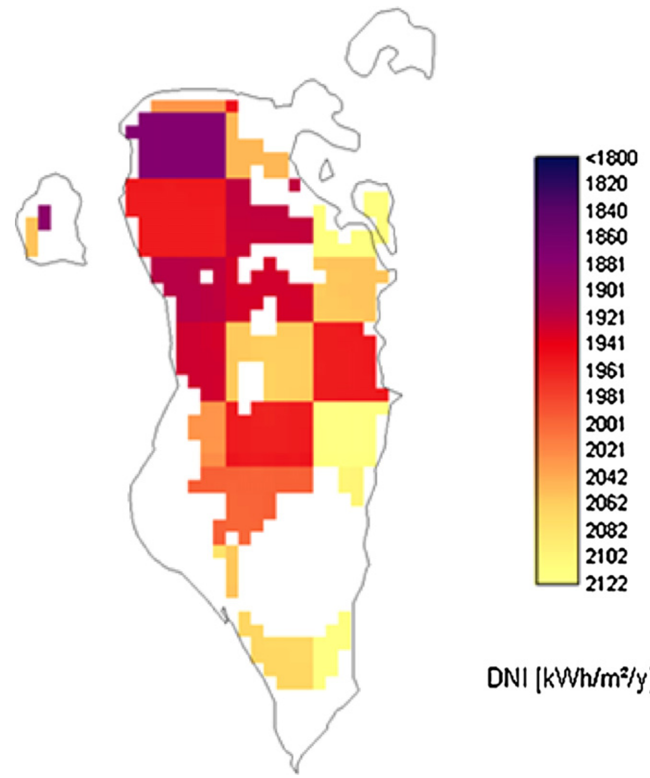


Fig. 7. The Concentrating Solar Thermal Potential in the Kingdom of Bahrain; total area 707 km^2; percentage of area needed from the main land for renewable electricity to fulfil the needs by 2050 is 3.5% (25 km^2). The technical potential is 36 TWh/y and the tentative CSP in 2050 is 3.5 TWh/y. The power demand in year 2000 was 5.8 TWh/y and the expected power demand in year 2050 is 6.9 TWh/y with power for water desalination equal to 1 TWh/y. The coastal potential is 21 TWh/y [21].

Surely, the rapid increase in world energy prices from 2003 to 2008 – where the price of barrel of oil reached nearly US$ 150 – combined with concerns about the environmental consequences of greenhouse gas emissions, has led to renewed interest in alternatives to fossil fuels – particularly, nuclear power and renewable resources. As a result, long-term prospects continue to improve for generation from both nuclear and renewable energy sources – supported by government incentives and by higher fossil fuel prices.

According to the IEO, from 2007 to 2035, the world renewable energy use for electricity generation grows by an average of 3.0% per year (Fig. 4), and the renewable share of world electricity generation increases from 18% in 2007 to 23% in 2035. Surprisingly, coal-fired generation increases by an annual average of 2.3% in the Reference case, making coal the second fastest-growing source for electricity generation in the projection. The outlook for coal could be altered substantially, however, by any future legislation that would reduce or limit the growth of greenhouse gas emissions. Generation from natural gas and nuclear power – which produce relatively low levels of greenhouse gas emissions (natural gas) or none (nuclear) – increase by 2.1 and 2.0% per year, respectively, in the Reference case.

Much of the world increase in renewable electricity supply is fueled by hydropower and wind power. Of the 4.5 trillion kWh of increased renewable generation over the projection period, 2.4 trillion kWh (54%) is attributed to hydroelectric power and 1.2 trillion kWh (26%) to wind. Except for those two sources, most renewable generation technologies are not economically competitive with fos-

Table 4
The electricity consumption in the GCC countries in 2005 and 2009 (in MWh/y) compared to world total, USA, China and EU.

Country	Consumption GWh/y (2005)	Consumption GWh/y (2009)	Population (2005)	W/person (2005)	Rate %
Bahrain	7614	8742	727,000	1195	12.9
SA	146,900	156,800	24,573,000	682	6.3
Qatar	12,520	13,190	813,000	1757	5.1
Oman	8661	11,190	2,567,000	385	22.6
UAE	52,620	57,880	4,500,000	1335	9.1
Kuwait	36,280	39,540	2,687,000	1540	8.2
Total GCC	264,595	287,342	35,867,000	1149	8.87
World	17,109,665	17,480,000	6,464,750,000	297	2.1
USA	3,872,598	3,892,000	298,213,000	1460	0.4
China	3,650,600	3,271,000	1,315,844,000	277	−11.6
EU	2,950,297	2,926,000	459,387,000	700	−0.8

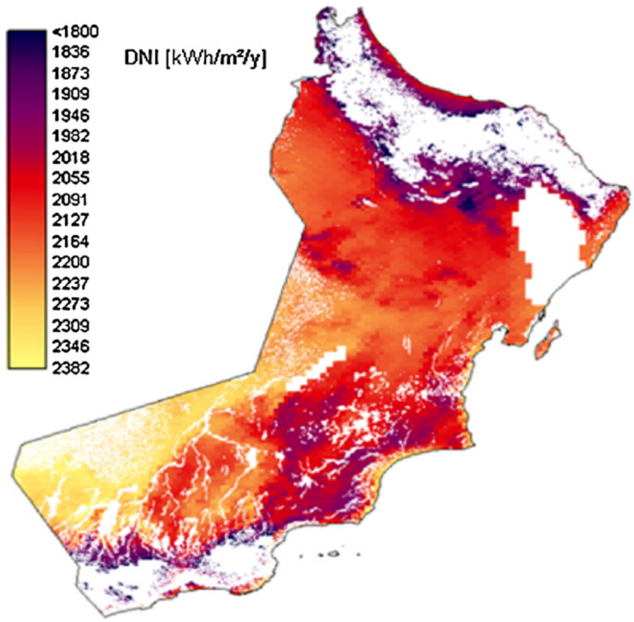


Fig. 8. The Concentrating Solar Thermal Potential in the Sultanate of Oman: total area 212,457 km^2; percentage of area needed from the main land for renewable electricity to fulfil the needs by 2050 is 0.2% (405 km^2). The technical potential is 20,611 TWh/y and the tentative CSP in 2050 is 22 TWh/y. The power demand in year 2000 was 8.5 TWh/y and the expected power demand in year 2050 is 35 TWh/y with power for water desalination equal to 6 TWh/y. The coastal potential is 497 TWh/y [21].

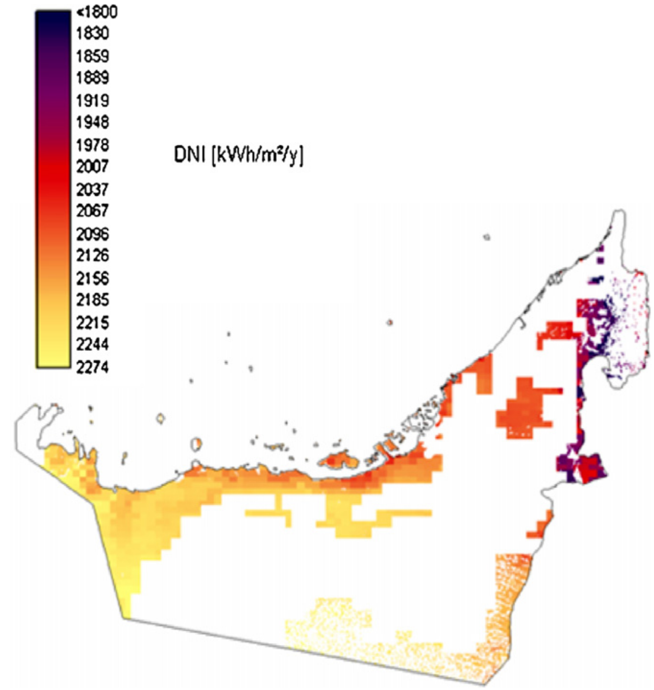


Fig. 9. The Concentrating Solar Thermal Potential in United Arab Emirates: total area 77,700 km^2; percentage of area needed from the main land for renewable electricity to fulfil the needs by 2050 is 0.1% (82 km^2). The technical potential is 2078 TWh/y and the tentative CSP in 2050 is 10 TWh/y. The power demand in year 2000 was 36 TWh/y and the expected power demand in year 2050 is 24 TWh/y with power for water desalination equal to 8 TWh/y. The coastal potential is 538 TWh/y [21].

sil fuels over the projection period, outside a limited number of niche markets.

Typically, government incentives or policies provide the primary support for construction of renewable generation facilities. Renewable energy, other than hydroelectricity and wind, including solar, geothermal, biomass, waste, and tidal/wave/oceanic energy – do increase at a rapid rate over the projection period (Fig. 5).

As of January 1, 2010, proved world oil reserves were estimated at 1354 billion barrels – 12 billion barrels (about 1%) higher than the estimate for 2009 [2] – 56% of the world's proved oil reserves are located in the Middle East and around 80% of the world's proved reserves are concentrated in eight countries, of which only Canada (with oil sands included) and Russia are not OPEC members (Table 2).

Total natural gas consumption worldwide increases 44% in the *IEO2010* Reference case, from 108 trillion ft^3 in 2007 to 156 trillion ft^3 in 2035. Demand for natural gas slowed in 2008 as the global economic recession began to affect world energy markets, and in 2009 world consumption of natural gas contracted by an estimated 1.1%.

The impact of the recession on natural gas use was especially evident in the industrial sector – the end-use sector with the highest level of natural gas consumption – where demand for natural gas declined by an estimated 6% from 2008 to 2009. Almost three-quarters of the world's natural gas reserves are located in the Middle East and Eurasia. Qatar, Russia and Iran together accounted for about 55% of the world's natural gas reserves as of January 1, 2010 (Table 3).

The world's largest gas field is Qatar's offshore North Field, estimated to have 25 trillion m^3 (9.0×10^{14} ft^3) of gas in place – enough to last more than 200 years at optimum production levels [3,4]. The second largest natural gas field is the South Pars Gas Field in Iranian waters in the Arabian Gulf. Connected to Qatar's North Field, it has estimated reserves of 8–14 trillion m^3 (2.8×10^{14} to 5.0×10^{14} ft^3) of gas.

2. Nuclear power

Electricity generation from nuclear power increases from about 2.6 trillion kWh in 2007 to 4.5 trillion kWh in 2035, as concerns about rising fossil fuel prices, energy security, and greenhouse gas emissions support the development of new nuclear generation capacity. High prices for fossil fuels allow nuclear power

Table 5
The performance of renewable energy indicators in the GCC countries. It represents the average renewable energy yield with which the national potential could be exploited [20,21].

Country	Hydro Full load (h/y)	Geo Temperature at 5 km depth	Bio Full load (h/y)	CSP Direct normal irradiance (kWh/m^2/y)	Wind Full load (h/y)	PV Global horizontal irradiance (kWh/m^2/y)	Wa/Ti Full load (h/y)
Bahrain	1000	100	3500	2050	1360	2160	4000
Kuwait	n.a[a]	100	3500	2100	1605	1900	4000
Oman	n.a[a]	100	3500	2200	2463	2050	4000
Qatar	n.a[a]	100	3500	2200	1421	2140	4000
KSA	n.a[a]	275	3500	2500	1789	2130	4000
UAE	n.a[a]	100	3500	2200	1789	2360	4000

[a] There were no well documented resource taken from literature.

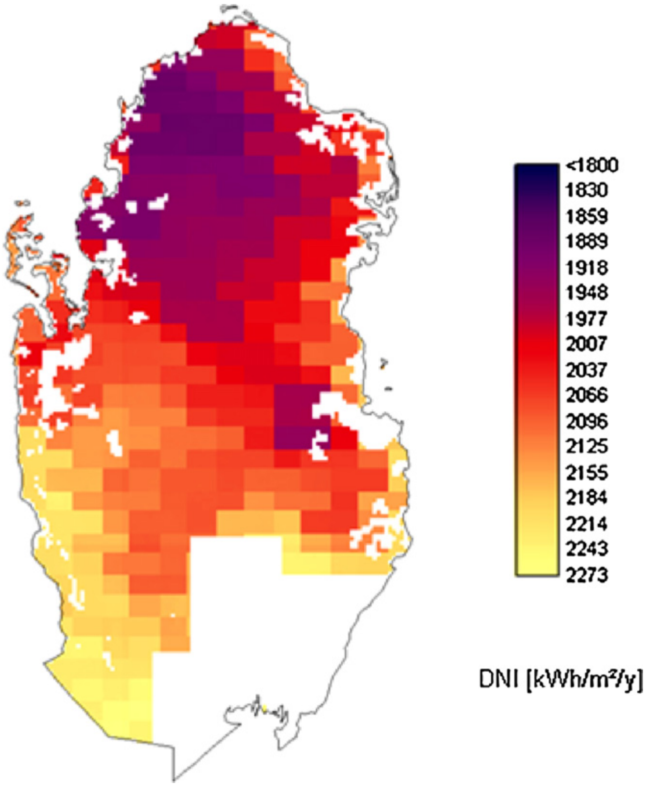


Fig. 10. The Concentrating Solar Thermal Potential in State of Qatar: total area 11,437 km^2; percentage of area needed from the main land for renewable electricity to fulfil the needs by 2050 is 0.2% (24 km^2). The technical potential is 823 TWh/y and the tentative CSP in 2050 is 2.8 TWh/y. The power demand in year 2000 was 9 TWh/y and the expected power demand in year 2050 is 5 TWh/y with power for water desalination equal to 1 TWh/y. The coastal potential is 324 TWh/y [21].

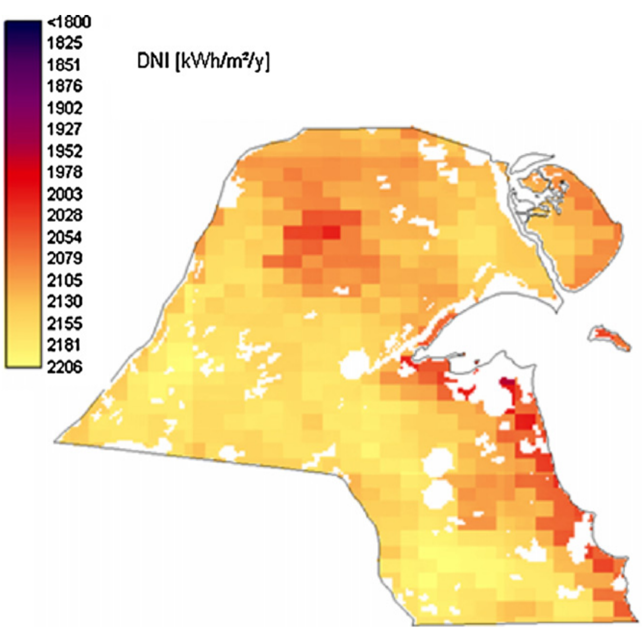


Fig. 11. The Concentrating Solar Thermal Potential in the State of Kuwait: total area 17,818 km^2; percentage of area needed from the main land for renewable electricity to fulfil the needs by 2050 is 0.5% (96 km^2). The technical potential is 1525 TWh/y and the tentative CSP in 2050 is 13 TWh/y. The power demand in year 2000 was 30 TWh/y and the expected power demand in year 2050 is 30 TWh/y with power for water desalination equal to 2.2 TWh/y. The coastal potential is 134 TWh/y [21].

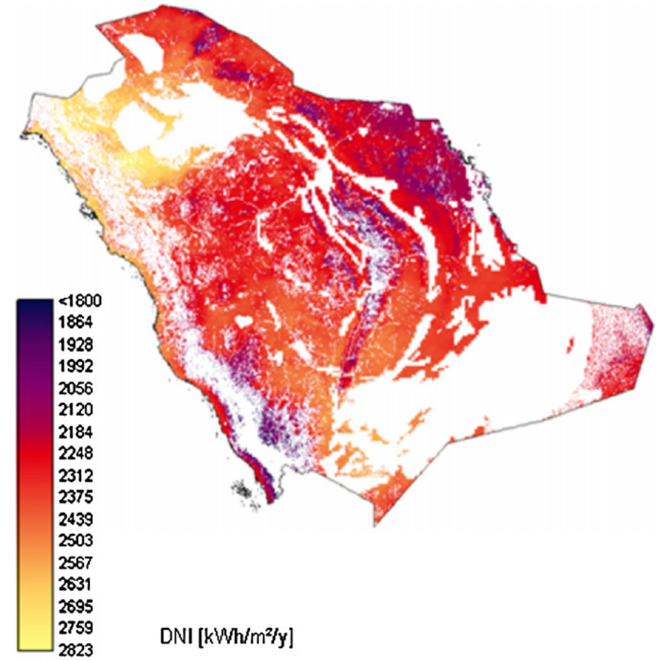


Fig. 12. The Concentrating Solar Thermal Potential in the Kingdom of Saudi Arabia: total area 224,000 km^2; percentage of area needed from the main land for renewable electricity to fulfil the needs by 2050 is 0.1% (1543 km^2). The technical potential is 125,260 TWh/y and the tentative CSP in 2050 is 135 TWh/y. The power demand in year 2000 was 119 TWh/y and the expected power demand in year 2050 is 305 TWh/y with power for water desalination equal to 99 TWh/y. The coastal potential is 2055 TWh/y [21].

to become economically competitive with generation from coal, natural gas, and liquid fuels despite the relatively high capital costs associated with nuclear power plants. Moreover, higher capacity utilization rates have been reported for many existing nuclear facilities and it is anticipated that most of the older nuclear power plants in the OECD countries and non-OECD Eurasia will be granted extensions to their operating lives.

Around the world, nuclear generation is attracting new interest as countries look to increase the diversity of their energy supplies and provide a low-carbon alternative to fossil fuels. Still, there is considerable uncertainty associated with nuclear power projections. Issues that could slow the expansion of nuclear power in the future include plant safety, radioactive waste disposal, rising construction costs and investment risk, and concerns that weapons-grade uranium may be produced from centrifuges installed to enrich uranium for civilian nuclear power programs. These issues continue to raise public concern in many countries and may hinder the development of new nuclear power reactors. Nevertheless, the *IEO2010* Reference case incorporates improved prospects for world nuclear power. The projection for nuclear electricity generation in 2030 is 9% higher than the projection published in last year's outlook.

On a regional basis, the *IEO2010* Reference case projects the strongest growth in nuclear power for the countries of non-OECD Asia. Non-OECD Asia's nuclear power generation grows at an average annual rate of 7.7% from 2007 to 2035, including increases of 8.4% per year in China and 9.5% per year in India. China leads the field with nearly 43% of worldwide active construction projects in 2009 and is expected to install the most nuclear capacity over the period, building 66 GW of net generation capacity by 2035 [3]. Outside Asia, nuclear generation grows the fastest in Central and South America, where it increases by an average of 4.3% per year. The nuclear generation forecasted in OECD Europe has undergone

Table 6
Area required for renewable energy electricity generation in 2050 [20,21].

Country	Hydro (km^2)	Geo (km^2)	CSP (km^2)	Bio (km^2)	Wind (km^2)	PV (km^2)	Total (km^2)	Country (km^2)	Area used (%)
Bahrain	0	0	21	0	2	2	25	707	3.5
Kuwait	0	0	78	0	0	18	96	17,818	0.5
Oman	0	0	133	0	244	29	405	212,457	0.2
Qatar	0	0	17	0	0	7	24	11,437	0.2
KSA	0	71	810	6	559	97	1543	2,240,000	0.1
UAE	0	0	60	1	0	21	82	77,700	0.1

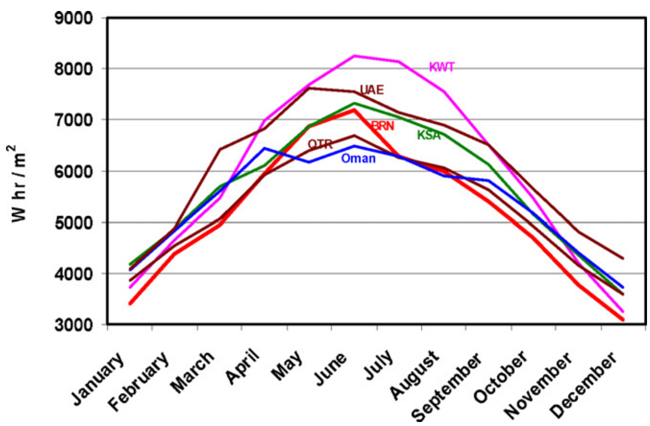


Fig. 13. Variation of the global solar radiation in GCC countries [24].

Fig. 14. We need an area of 350 km^2 from the land of GCC countries, to install CSP (efficiency of 50% and solar radiation of 500 W/m^2 and 9 daily average sunshine hours), to produce annually 287,342 GWh – which is equal to total electricity consumed in 2009 in GCC countries.

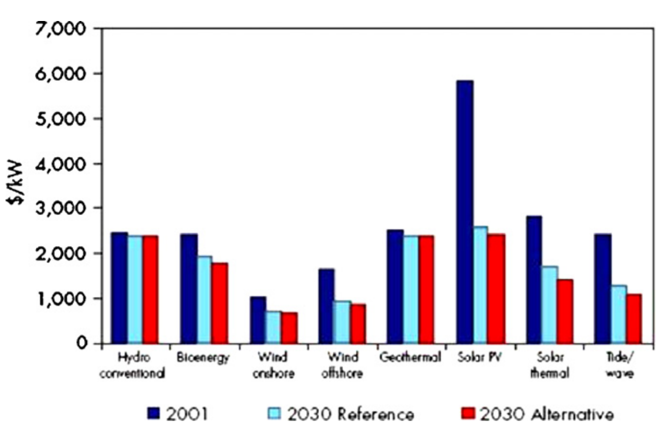


Fig. 15. Cost of kW from different renewable energy technologies [26].

a significant revision from *IEO2009*, because multiple countries in the region are reversing their anti-nuclear policies. In the *IEO2010* Reference case, nuclear generation worldwide increases by 2.0% per year.

To address the uncertainty inherent in projections of nuclear power growth in the long term, a two-step approach is used to formulate the outlook for nuclear power. In the short term (through 2020), projections are based primarily on the current activities of the nuclear power industry and national governments. Because of the long permitting and construction lead times associated with nuclear power plants, there is general agreement among analysts on which nuclear projects are likely to become operational in the short-term. After 2020, the projections are based on a combination of announced plans or goals at the country and regional levels and consideration of other issues facing the development of nuclear power, including economics, geopolitical issues, technology advances, environmental policies, and uranium availability.

On 17 March 2010, (http://www.scidev.net/en/new-technologies/saudi-arabia-creates-city-for-nuclear-and-renewable-energy.html), United Arab Emirates announced plans to establish the Gulf Nuclear Energy Infrastructure Institute, in Abu Dhabi. This educational institution will provide civilian nuclear-energy programmes in the Gulf region with a source of local nuclear-energy professionals.

3. Electricity generation in the GCC countries

Electricity generation in the Middle East region grows by 2.5% per year in the Reference case of IEO2010, from 0.7 trillion kWh in 2007 to 1.3 trillion kWh in 2035. The region's young and rapidly growing population, along with a strong increase in national income, is expected to result in rapid growth in demand for electric power. Iran, Saudi Arabia, and the United Arab Emirates (UAE) account for nearly 75% of the regional demand for electricity and demand has increased sharply over the past several years in each of the countries. From 2000 to 2007, Iran's net generation increased by an average of 7.9% per year; Saudi Arabia's by 6.1% per year; and the UAE's by 9.6% per year.

The Middle East depends on natural gas and petroleum liquid fuels to generate most of its electricity and is projected to continue that reliance through 2035 (Fig. 6). In 2007, natural gas supplied 57% of electricity generation in the Middle East and liquid fuels 35%. In 2035, the natural gas share is projected to be 68% and the liquid fuels share 21%.

Other energy sources make only minor contributions to electricity supply in the Middle East. Iran and the UAE are the only ones projected to add nuclear capacity. Other Middle Eastern countries recently have expressed some interest in increasing both coal-fired and nuclear generation, however, in response to concerns about diversifying the electricity fuel mix and meeting the region's fast-paced growth in electricity demand. For example, Oman announced in 2008 that it would construct the Arabian Gulf's first coal-fired power plant at Duqm [5]. According to the plan, the 1-GW plant will power a water desalinization facility and will be fully operational by 2016 [6]. According to IEO 2010, the UAE, Saudi Arabia, and Bahrain also have considered adding coal-fired capacity [7]; if this is true, this mean that GCC countries are following energy mix policy.

In addition to Iran, several other Middle Eastern nations have announced intentions to pursue nuclear power programs in recent

Table 7
Solar versus wind powers in the Arabian Gulf countries (W/m^2) [22–25].

Country	Solar energy (Wh/m^2)	Sunshine duration (h)	Solar power (W/m^2)	Wind power (W/m^2)	Solar/wind
Bahrain	5180	9.2	563	78	7.2
Saudi Arabia	5670	8.7	683	71	9.6
Kuwait	5990	8.9	673	140	4.8
Qatar	5260	9.3	565	85	6.6
UAE	5078	8.8	577	57	10.1
Oman	5410	9.6	564	141	4

Table 8
Monthly and annual mean global radiation in MJ/m^2/day [22].

Country	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual (average)
UAE	15.48	18.0	20.52	24.12	28.08	27.36	25.2	24.12	23.4	20.52	17.28	14.4	21.6
Bahrain	12.96	17.28	17.28	21.96	24.84	26.64	28.44	22.68	20.88	17.64	14.04	10.8	19.62
SA	12.6	16.56	18.36	19.8	20.16	21.96	21.96	21.24	20.52	19.08	16.56	12.96	18.36
Oman	16.56	17.64	20.16	20.88	21.96	18.72	11.88	10.80	16.56	19.44	17.28	15.84	17.28
Qatar	13.32	15.84	17.64	20.52	22.32	23.4	21.6	20.88	19.8	15.12	14.76	12.6	18.36
Kuwait	11.16	14.76	19.8	22.32	25.56	28.44	27.0	25.56	22.32	17.28	12.24	10.44	19.8

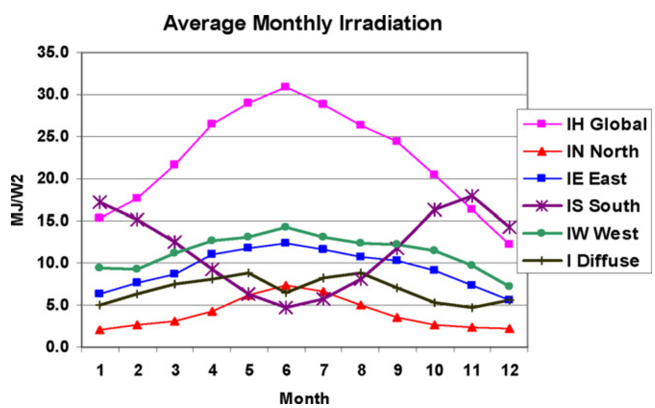


Fig. 16. The monthly variation of solar radiation: total solar radiation on a horizontal surface (IT), total solar radiation on vertical surface facing north (IN), East (IE), South (IS), West (IW), as well as the diffused solar radiation on a horizontal surface (I Diffuse) in Bahrain in 2001[27].

Fig. 17. Using 11,000 wind turbines, each rated 5 MW, will be enough to provide 287 TWh annually – equal to the electricity consumed in the GCC countries in 2009. This is assuming that the wind turbines will operate 60% of time per year at full capacity. 5 rows will be needed along the GCC coast (2221 km long) and 5 km deep in the sea.

years. In 2007, Gulf Cooperation Council countries (Saudi Arabia, Kuwait, Bahrain, the United Arab Emirates, Qatar, and Oman) completed a feasibility study, in cooperation with the International Atomic Energy Agency, of the potential for a regional nuclear power and desalinization program, while also announcing their intention to pursue a peaceful nuclear program [8].

The UAE government in 2008 announced plans to have three (total of 1.5 GW) nuclear power plants completed by 2020 and has since signed nuclear cooperation agreements with France, Japan, the United Kingdom, and the United States [9]. In December 2009, the Emirates Nuclear Energy Corporation in the UAE selected a South Korean consortium to build four nuclear reactors, with construction planned to begin in 2012 [10]. Jordan also has announced its intention to add nuclear capacity [11], and in 2009 the Kuwaiti cabinet announced that it would form a national committee on nuclear energy use for peaceful purposes [12]. Even given the considerable interest in nuclear power that has arisen in the region, however, *IEO2010* expects that economic and political issues, in concert with the long lead times usually associated with beginning a nuclear program, will mean that any reactors built in the Middle East over the course of the projection will be located in Iran or the UAE.

Although there is little economic incentive for countries in the Middle East to increase their use of renewable energy sources (the renewable share of the region's total electricity generation increases from only 3% in 2007 to 5% in 2035), there have been

Fig. 18. A solar thermal project (100 MW) at Abu Dhabi (Shams 1) will contribute directly towards Abu Dhabi's target of achieving 7% renewable energy power generation capacity by the year 2020.

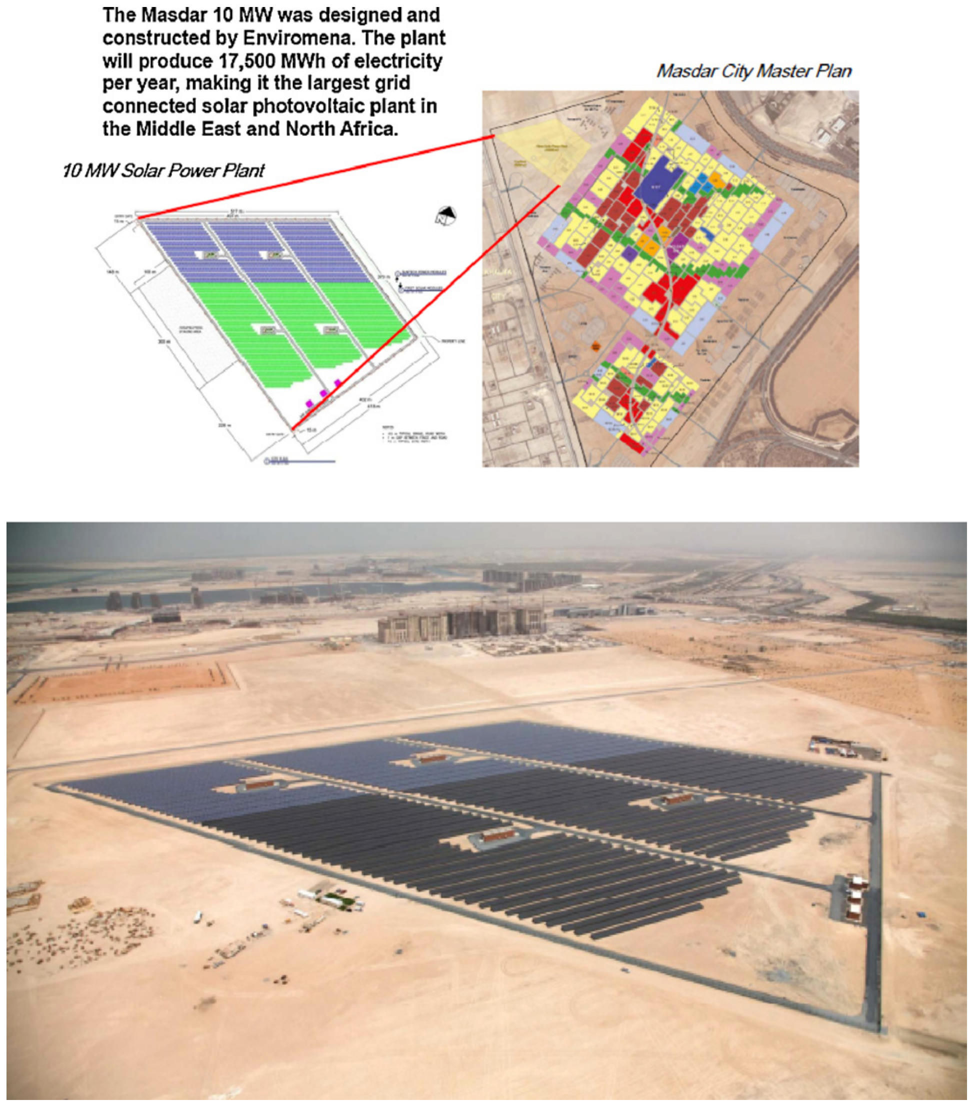


Fig. 19. The Masdar City plan (top) with 10 MW PV power plant (bottom). It is 218,000 m^2 field containing 87,000 solar module (Single crystalline supplied by Suntech – Blue or Light colour and thin film supplied by First Solar – Black or Dark colour) installed to light weight steel racking over 300 km wiring. The picture was of mid April 2009 shows completion of 75%. Now the project is nearly completed.

some recent developments in renewable energy use in the region. Iran, which generated 10% of its electricity from hydropower in 2009, is developing 94 new hydroelectric power plants, 5 of which are expected to come on line before March 2010 [13].

In the GCC countries, construction also continues on Masdar City in Abu Dhabi, a "zero carbon" city that will be powered by 190 MW of PV cells and 20 MW of wind power [14]. The city, which was chosen as the interim headquarters of the International Renewable Energy Agency (IRENA) and currently has a 10-MW PV array, is on track to be completed in 2016 [15].

Table 4 illustrates the electricity consumption in the GCC countries in 2005 and 2009 (in MWh/y) and compares their total (264,595 GWh in 2005 and 287,342 GWh in 2009) with the World Total (17,109,665 MWh in 2005 and 17,480,000 in 2009), USA (3,872,598 GWh in 2005 and 3,892,000 GWh in 2009), China (3,650,600 GWh in 2005 and 3,271,000 GWh in 2009) and the European Union, EU (2,950,297 GWh in 2005 and 459,387,000 GWh in 2009).

Table 4 shows that electricity consumption in GCC countries is only 0.5% of the world (0.5% of its population), 9.8% of EU (7.8% of their population), 8.8% of China (2.7% of their population) and 7.4% of USA (12% of their population) in 2009. The rate of increase in electricity consumption in GCC countries from 2005 to 2009 was 8.87% (largest rate was in Oman, 22.6%, and least in SA, 6.3%) with average per person of 1149 W – which is 3.9 times the world average, 0.8 of USA average, 4.2 of China average and 1.7 of EU average in 2009.

The GCC countries produce electric power and consume electricity it at a very high rate. According to CIA World Fact Book in 2009, Saudi Arabia, SA, is ranked worldwide 16 in electricity consumption (156,800 GWh), Kuwait is ranked 53 (39,540 GWh), United Arab Emirate,UAE, is ranked 41 (57,880 GWh), Oman is ranked 80 (11,190 GWh), Qatar is ranked 76 (13,190 GWh) and Bahrain is ranked 88 (8742 GWh) [16].

4. The investment in power in GCC countries

According to Gulf Construction Magazine [17], the electricity network currently serving the four GCC countries (Qatar, Bahrain, Kuwait and Saudi Arabia) will play a key role in meeting demand for an additional 55,000 MW of power through year 2015. The first phase of the grid, which was launched during the second half of 2009, has already been completed. The UAE could be added to the network within this year. The regional (the six GCC coun-

Fig. 20. Case study – shams tower, yas marina circuit. It is a 291 kWp PV solar electricity [29].

tries) power capacity is at around 75,000 MW, a projected 9.5% growth in annual demand will require more electricity and energy projects. Qatar government's by itself is investing $140-billion budget for infrastructure (electricity) and business expansion in 2010.

These countries use the electricity mainly for air-conditioning and water production to overcome the harsh environment. This is made by burning natural gas and light hydrocarbon fuel, which are depletable and exhaustable (non sustainable) and polluting. The demand on energy is expected to grow substantially due to the growing investment, especially in building and construction sector (sky scrapers and artificial tourist islands). The Projected Additional

Table 9
Cost of kWh from PV electricity for either ground mount and roof top installed in a high solar radiation country (Dubai and Abu Dhabi) [29].

	Ground mount	Roof mount
Cost per Wp	$3.50–$4.00 US/Wp	$4.50–$5.50 US/Wp
Power Output	1650 kWh/kWp	1650 kWh/kWp (10 tilt) 1540 kWh/kWp (when flat)
Cost of electricity (25 years)	$0.22–$0.27 US/kWh	$0.30–$0.35 US/kWh
System lifetime	25 years+	25 years +

Electricity Capacity needed by 2010 in GCC countries is as follows [18]:

- Bahrain – 1200 MW at an estimated cost of US$ 900 million
- Kuwait – 3400 MW at an estimated cost of US$ 2.5 billion
- Oman – 1100 MW at an estimated cost of US$ 800 million
- Qatar – 800 MW at an estimated cost of US$ 600 million
- Saudi Arabia – 20,000 MW at an estimated cost of US$ 15 billion
- United Arab Emirates – 6600 MW at an estimated cost of US$ 5.1 billion

In this section we shall look at energy for sustainable development in the GCC countries, i.e. looking at the energy that takes into consideration the Economic, Social and Environmental Triangle and how policy makers in these countries maintain the prosperity of the nation without breaking any side of this triangle. The GCC countries in 2010 are expanding in electricity-generating capacity and are expected to invest USD 200 billion to 250 billion in between 14 and 20 energy projects by 2020 [19] distributed as follows:

i. Kuwait plans to spend USD 15 bn to double power capacity to 20 GW by 2020. Kuwait (and other GCC countries), suffers from power cuts each summer, plans to spend US$ 15 billion (Dh55.09bn) to double power capacity to 20,000 MW by 2020.
ii. Saudi Arabia could see power consumption rise 57% to 65 GW by 2018 (need to boost capacity by 3000 MW a year).
iii. Abu Dhabi is planning for 4 nuclear reactors for a total cost at a total cost of nearly USD 40 billion (for year 2020). Masdar City in Abu Dhabi costs is a $22 billion carbon-free city with 10 MW PV, enough electricity for 55,000 residents.
iv. Dubai Electricity and Water Authority will invest nearly USD 8 billion in the next five years to triple power and water output.
v. Bahrain needs nearly to have 10 GW of electricity by 2020.

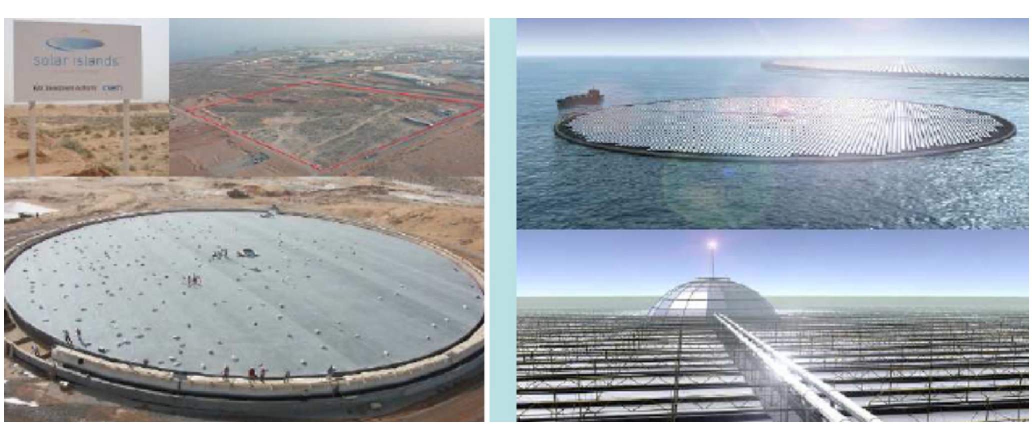


Fig. 21. A 1 MW rotating Solar island Project in Ras Al Khaima, UAE. The circular Solar Islands in Ras Al Khaima, UAE with a diameter of 5 km and height of 20 m consisting steam storage, carrying the termosolar concentrator solar power (CSP) panels placed on a membrane. The platform can be floated on high sea or land [30,31].

Fig. 22. On the top roof of the offices at Burj Khalifa there are 378 collector panels, each 2.7 m^2 in area (total area of 1021 m^2), can heat the entire 140,000 L of water in approximately 7 h of day time solar radiation. The solar powered water brings energy savings equivalent to 3200 kW per day and 690 MWh of energy per annum [32].

By year 2020, the GCC population is forecasted to reach 53.5 million, a 30% increase over 2000. Accordingly, the Economist Intelligence Unit (EIU), over the same period, the region's real GDP is expected to grow by 56%.

Despite controlling 40% of the world's known oil reserves and 23% of proven natural gas reserves, the GCC must conserve hydrocarbon resources not only because they are finite sources, but because conservation makes financial sense. In contrast, water is an extremely scarce resource in the GCC, which is one of the world's most arid regions.

The GCC countries are gearing up for one of the biggest expansions of electricity-generating capacity in history, even as they confront difficulties in securing debt finance and fuel for the plants. Power officials are looking at a doubling or tripling of consumption in the next two decades, but facing acute shortages of natural gas. With the easing of the economic crisis and renewed growth, this year could become an especially big year for the power industry.

Saudi Arabia could see power consumption rise 57% to 65,000 MW by 2018. The kingdom will need to boost capacity by 3000 MW a year, which is equivalent to the output of two of the nuclear reactors planned for Abu Dhabi, at a total cost of $54.7bn. It will burn 27% more oil a year, decreasing the amount available for export.

In Bahrain, power consumption is expected to more than double by 2030, electricity demand currently peaks at a maximum of 2234 MW a day, but was expected to surge to 5700 MW a day by 2030.

Resources show that the US$ 2 trillion worth of projects in GCC countries in 2010 is planned. This is mainly for construction and power. In 2009, almost US$ 52 billion worth of contract was awarded to GCC countries. The total value of the infrastructure con-

Table 10
Major previous renewable energy projects conducted in Saudi Arabia [33].

Projects	Location	Duration	Applications
350 kW PV system (2155 MWh)	Solar Village	1981–1987	AC/DC electricity for remote areas
350 kW PV hydrogen production plant (1.6 MWh)	Solar Village	1987–1993	Demonstration plant for solar hydrogen production
Solar cooling	Saudi universities	1981–1987	Developing of solar cooling laboratory
1 kW solar hydrogen generator (20–30 kWh)	Solar Village	1989–1993	Hydrogen production, testing and measurement (laboratory scale)
2 kW solar hydrogen (50kWh)	KAU, Jeddah	1986–1991	Testing of different electrode materials for solar hydrogen plant
3 kW PV lest system	Solar Village	1987–1990	Demonstration of climatic effects
4 kW PV system	Southern regions of Saudi Arabia	1996	AC/DC electricity for remote areas
6 kW PV system	Solar Village	1996–1998	PV grid connection
Solar sea water desalination			
PV water desalination (0.6 m^3 per hour)	Sadous Village	1994–1999	PV/RO interface
Solar-thermal desalination	Solar Village	1996–1997	Solar distillation of brackish water
PV in agriculture (4 kWp)	Muzahmia	1996	AC/DC grid connected
Long-term performance of PV (3 kW)	Solar Village	Since 1990	Performance evaluation
Fuel cell development (100–1000 W)	Solar Village	1993–2000	Hydrogen utilization
Internal combustion engine (ICE)	Solar Village	1993–1995	Hydrogen utilization
Solar radiation measurement	12 stations	1994–2000	Saudi solar atlas
Wind energy measurement	5 stations	1994–2000	Saudi solar atlas
Solar dryers	Al-Hassa,Qatif	1988–1993	Food dryers (dates, vegetables, etc.)
Two solar-thermal dishes (50 kW)	Solar Village	1986–1994	Advanced solar stirling engine
Energy management in buildings	Dammam	1988–1993	Energy conservation
Solar collectors development	Solar Village	1993–1997	Domestic, industrial, agriculture
Solar refrigeration	Solar Village	1999–2000	Desert application

Fig. 23. The plant will use ultra-high concentrator photovoltaic cells similar to this concentrated photovoltaic solar panel developed by IBM Research [37].

Fig. 24. 2 MW PV and 2MW equivalent of solar thermal at KAUST), off-setting 5.7% of total campus energy demand [39].

tracts increased from US$ 15 in 2008 to US$ 15 billion in 2009. It has to be noted that Building and Construction Sector had drawn lot of total GCC countries' energy (nearly 60%).

Gulf countries have committed over $100 billion to boost power sector. But the electricity demand in the region has been growing at around 8–9% per year – faster than the growth recorded in any other region of the world.

Over the next 10 years these countries will need to add 100 MW of additional installed power to support economies that are running at twice the growth rate of the major advanced economies. All the six countries of the Gulf Cooperation Council (GCC) face the challenge of meeting the increasing electricity needs of a rapidly expanding infrastructure and increasing amounts of energy-intensive industrial development.

According to a report on the GCC in 2020: resources for the future – written by the Economist Intelligence Unit and sponsored by the Qatar Financial Centre Authority – the main findings were the following [19]:

1. GCC governments are overhauling the way they manage hydrocarbons. Most governments plan to reserve a greater proportion of crude oil to produce value-added and refined products for export, and to use natural gas to fuel power plants.

2. Conservation of electricity and gas is a must. Blackouts and brownouts are already common during peak times, and energy subsidies represent an increasing cost for GCC governments. While governments realize that current consumption patterns are not sustainable, curtailing subsidies remains a political challenge.

3. Investment in renewable fuels is on the rise. To diversify their economies and benefit from increased global demand for renewable fuels, GCC states will invest in alternatives such as solar and nuclear power. These resources will help them to meet the shortfall in electricity supplies, and free up oil and gas for export.

4. Investment in mineral development is rising, with foreign companies also playing a role. Alongside investments in energy, GCC governments are investing more in exploiting non-oil minerals such as gold, silver, iron ore, copper and bauxite. The aim is to diversify economically and create jobs.

5. The region faces potentially serious water shortages. Rising temperatures and expanding populations will place increasing pressure on the Gulf's water supplies, which are already heavily reliant on desalination. At present, the vast majority of water goes into agriculture, a sector that provides less than 5% of GDP. Water use will need to be urgently addressed.

6. Investments in farmland abroad are needed to ensure food security, but must be structured carefully to avoid conflicts with host governments. Among the risks to be managed in such investments are: ensuring a transparent land valuation and transfer process, ensuring a broader range of stakeholders than just governments, providing clear and visible benefits for local communities, and respecting the host country's trade rules and export regulations.

5. Renewable energy potential in the GCC countries

The GCC countries lie within the solar belt, i.e. region abundant with high solar radiation (more than 6 kWh/m^2/day) and clear sky more than 80% throughout the year. It is in the arid zone. It lies at longitude from 45 to 58°E and latitude from 20 to 30°N. This means that it is scarce in rainfall. The natural water per capita is less than 200 m^3 per year (absolute scarcity level).The average annual temperature is not less than 26 °C. Eight months of the year are not lying in the comfort zone, where 6 months require cooling (air conditioning) and 2 months require heating. Table 5 shows the potential of renewable energies in GCC countries [20]. Table 6 illustrates how small percentage of the land area of each GCC countries can fulfil the electricity need in 2050.

It has to be released that an area of 90,600 km^2 or only 0.1% of Sahara's land mass could power the whole world with green electricity. An area of 15,500 km^2 of solar panels (size of Connecticut, USA) can provide sufficient electricity for Europe (population of 500 million).

To demonstrate the wealth and importance of the solar energy in GCC countries, Figs. 7–12 were made. It shows how the concentrated solar power (CSP) could meet the electrical and water demand for the GCC countries by 2050 compared to consumption of year 2000 [20]. The technical potential in this figure is the accessed CSP for power generation by the present state of the art technology and it is sized by the direct normal incidence (DNI) solar radiation less 1800 kWh/m^2/y. The tentative CSP in 2050 is the expected power to be use in a normal trend (not force major case). The coastal potential is the power from CSP installed on relatively flat areas (<20 m of sea level).

The GCC region has also a good potential in total solar radiation (for PV application) and the direct solar radiation (for CSP application) and in wind speed (for wind power application). Studies [22–24] have shown that daylight at 25°N exists about 4449 h/year and that 70% of this is sunshine. For example, latest measurements in Abu Dhabi, UAE, (which housing MASDER and IRENA) show that the daily maximum direct beam radiation is 937 W/m^2 (recorded on February 22, 2007) while the highest daily average solar radiation was 730 W/m^2 (was recorded on March 30, 2007).

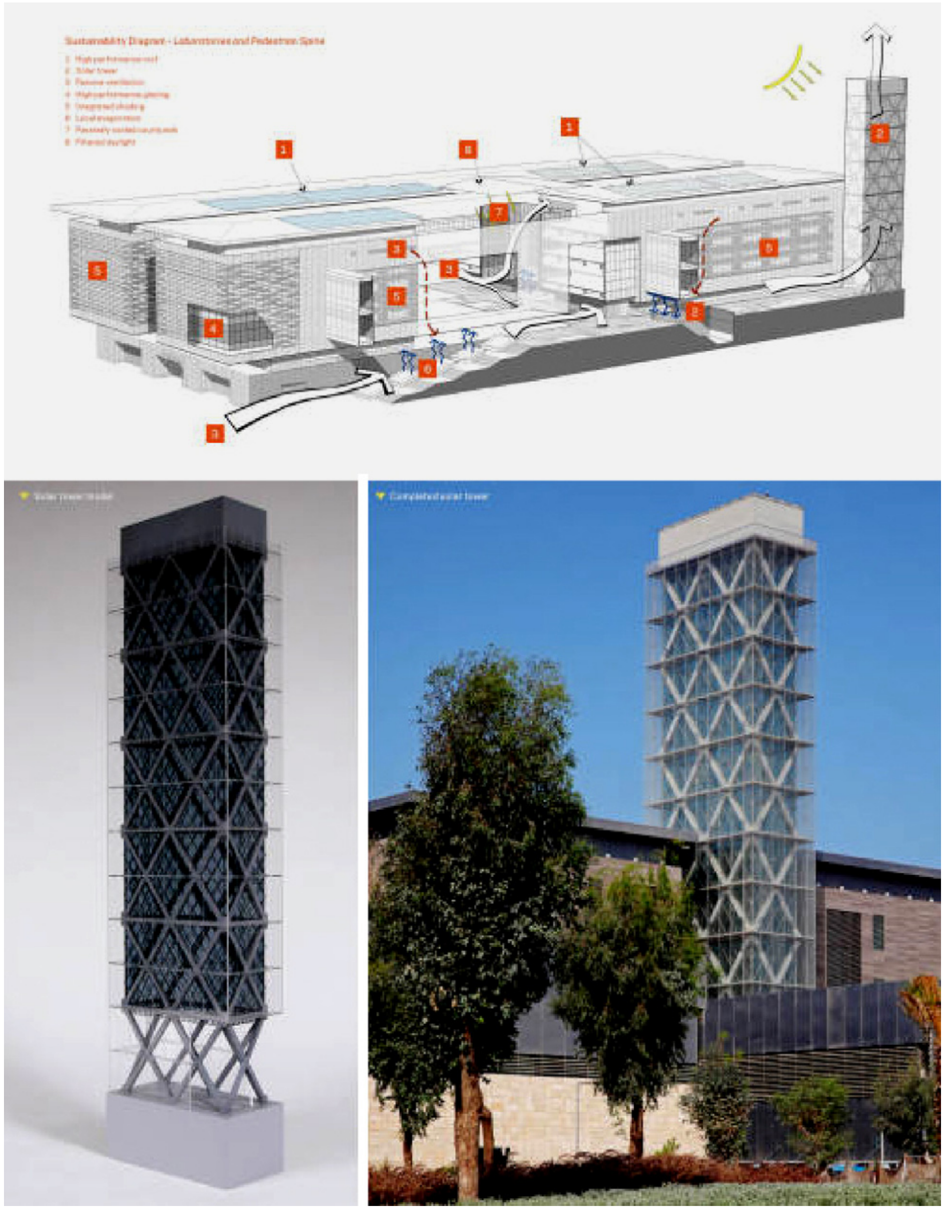


Fig. 25. Two solar chimneys at KAUST are capable in producing pressure difference in the air making the campus comfortably ventilated and offering breeze, i.e. reducing energy for cooling [40].

The daily mean solar radiation values in Abu Dhabi were high during the period from 13 March to 28 July. The highest recorded monthly average daily radiation was 493.5 W/m^2 (in the month of May) while the lowest monthly average daily solar radiation was 302.6 W/m^2 (in the month of August). The ground based solar and wind power data are presented in Table 7 [22–25] and in Table 8 [22].

The wind energy data in Table 7 is at a height of 10 m but the calculated data at 80 m [25] shows that it is higher than at 10 m by nearly 40% – as the case of Oman. The tentative estimated annual net output wind energy in Oman, from a 2 MW wind turbine, at Thumrait location was 5820 MWh/year and at Quiroon Hariti location was 6470 MWh/year [25], i.e. highly dependent on the location.

Fig. 13 shows the variation of the global solar radiation in GCC countries [24] – which is relatively equal 1.1 barrel of oil equivalent per m^2. The radiation is highest in Kuwait, in June–July, (8200 kWh/m^2) and lowest in Oman (6400 kWh/m^2). The radiation is low in January–December (4200 kWh/m^2 in UAE and 3200 kWh/m^2 in Bahrain).

The total area of the GCC countries is 2.5 million km^2. Taking into consideration that the electricity consumption in the GCC countries in 2009 is 287,342 GWh and assuming PV's has efficiency 15% – operating 24 h using batteries – with solar radiation of 500 W/m^2 with sunshine duration of 9 h then we need nearly only 1165 km^2 of GCC lands to fulfil this electricity need (use only 0.05% of GCC land area which is 2.5 million km^2).

In using CSP which has a capacity factor (efficiency) of 20–90% – which is higher than PV (15–25%) – then the needed area will be only 350 km^2 for efficiency of 50% (Fig. 14). This means it is cheaper to install CSP for electricity production than PV as the former costs US$ 6000 per kW and the later costs US$ 3000 per kW – refer to Fig. 15 [26].

Luckily, there were an actual measured data of solar radiation incident on vertical surfaces facing different geographical directions (North, East, South and West) for Bahrain. These data were a fruit of the collaboration between Napier University, Scotland, UK and University of Bahrain, Kingdom of Bahrain. The instrument was installed on the roof of the administrative building of Bahrain

Fig. 26. Qatar has submitted their bid to World Cup 2022 and 2026, which includes a slew of solar powered stadiums [45]. VIVA team had made a 3 days visited to Qatar on 16 September 2010 for presentation and inspection.

Meteorological Directorate and was taken for one year (Fig. 16). It is very interesting to note that the insolation on a south facing surface reaches as high as 17 MJ/m^2 in winter season and 5 MJ/m^2 for summer season while the roof (horizontal surface) receive as high as 32 MJ/m^2 in peak summer season and 12 MJ/m^2 in peak winter season, i.e. average of 21 MJ/m^2 [27]. The diffuse radiation during that year (2001), in Bahrain, was only 8 MJ/m^2 (25% of the total solar radiation). This means that 75% of the insolation in Bahrain is direct (suitable for CSP application) and the remaining (25%) is diffused radiation (PV thin film can still function on this type of radiation).

Meanwhile, installing off-shore 5 MW wind turbines, with 60 m blade size on the GCC coast (11,000 wind turbines installed on the east coast of the GCC – length of 2221 km) making nearly 5 rows – each row separated by 1 km from the other and 5 km deep in the Arabian Gulf – will fulfil the electricity need for all GCC countries (287 TWh, annually) – assuming that these wind turbines will operate at full capacity only 60% annually (Fig. 17).

6. Renewable energy projects in GCC countries

6.1. United Arab Emirates

Electricity demand in UAE is expected to more than double within the next decade, rising from 16,000 MW to 40,000 MW by the end of 2020. Therefore, many projects in renewable energy were made and planned. Among them is the establishment of Masdar company – which is the renewable energy arm of UAE. The company has already invested $250 million in clean-tech companies from around the world, and expects to launch a second and third fund in the near future. Masdar may have $15 billion to spend, although UAE earns $225 million in revenue from petroleum every day. The following steps were made:

1. At the Future Energy Summit, Masdar officials announced a deal with British Petroleum and Rio Tinto for the emirate to build one of the world's first commercial hydrogen power plants, a 500-MW operation slated to cost at least $2 billion.

2. Masdar City will be 6 km^2 walled community designed to be car-free and served by magnetic trains. A desalinization plant for water will run on solar power, and conservation needs will keep water use 60% below the norm; all waste will be composted and recycled – a major feat in a world that's increasingly awash in trash. If all goes according to Foster's plan, 50,000 people will be living in the city by 2016, many of them working for the renewable-energy businesses.

3. Recently [28], contracts have been let for a 100 MW solar power facility that will be built near the capital of the United Arab Emirates (UAE). Masdar (Abu Dhabi's renewable energy company) – called Shams 1 – will work with Abengoa of Spain (a company that has 493 MW in operation and construction using trough, tower and photovoltaic technologies) and Total (active in solar energy since 1983) of France to build Shams 1, at a cost of US$ 500 million to US$ 700 million (Total and Abengoa will own 20% each of the project, with Masdar controlling 60%). The facility will install 768 Solar Parabolic Mirrors, or known as concentrated solar power (CSP) – focusing sunlight that is concentrated by mirrors to heat a coolant which then generates high-pressure steam to drive a conventional steam turbine – to be the largest concentrated solar power plant in the world, extending over 2.5 km^2 and generating green power for 62,000 homes.

Shams 1 will be the world's largest concentrated solar power plant in the Middle East (Fig. 18).

Construction will begin late 2010 and be completed within two years. This project was made because Abu Dhabi has a target of 7% of electricity to be generated from renewable energy facilities

Table 11
Cost analysis of 20 MW wind electricity in Oman [50].

Item	Mill USD		USD
	Unit price	Quantity	Amount
Wind turbine			
Wind turbine, 2.0 MW	3.00	10	30.0
Monitoring system	0.20	1	0.2
Civil works			
Wind turbine foundation	0.15	10	1.5
Access roads (5 km)	0.30	1	0.3
Control room, facilities	0.50	1	0.5
Electrical works			
Main substation	1.00	1	1.0
Feeder	0.05	4	0.2
Transformer	0.30	15	4.5
Distribution net work	0.50	1	0.5
Other costs			
Insurance	0.10	1	0.1
Shipment	0.10	1	0.1
Design, supervision	0.20	1	0.2
Total, 20 MW wind farm			38.6
Total per MW installed			1.9

by 2020 to fulfil its commitment for hosting IRENA (International Renewable Energy Agency) in Abu Dhabi.

Construction of the plant, which will cover an area of 2.5 km^2 and have a 100 MW capacity, will begin in November 2010 and be completed in approximately two years. This project is expected to cost US$ 600 million (€504.2 million). This plant will offset 170 thousand tons of CO_2, annually. Masdar will hold a 60% stake in the project, while Total and Abengoa Solar will each have 20%.

Shams 1 is a solar field consisting of 768 parabolic trough collectors. Construction is set to begin during the third quarter of 2010, and is expected to take about two years.

Shams 1 is registered as a project under the UN's Clean Development Mechanism (CDM), and is eligible for carbon credits. It is the first CSP plant registered under the CDM and the second project registered for Masdar. The plant will displace about 175,000 tons of carbon dioxide a year, equivalent to planting 1.5 million trees or removing 15,000 cars from Abu Dhabi's roads. It has to be noted that Algeria already has a 150 MW CSP plant planned for 2012, with grand plans of exporting up to 6 GW of solar power to southern Europe by 2020.

4. Masdar City will be mostly solar-powered using traditional rooftop photovoltaic panels as well as from a 20 MW wind farm. The city will get its water from a solar-powered desalination plant.

5. Masdar, has invited 22 leading international manufacturers of solar photovoltaic (PV) technology to test their products where it counts, in the environmental conditions of Abu Dhabi. Later, they had installed 10 MW of PV panels both thin film and single crystal silicon (Fig. 19). It is 218,000 m^2 field containing 87,000 solar module installed to light weight steel racking over 300 km wiring.

6. In Dubai, Shams Tower project at Yas Marina F1 Circuit in Dubai (Fig. 20) was made.

It is a VIP viewing tower for the 2009 Formula 1^{TM} Etihad Airways Abu Dhabi Grand Prix with the following features:

- 2 m × 1250 m "wing" structures provide car park shading; total area of PV cover 2500 m^2.
- 1120 PV modules each rated 260 W Suntech (polycrystalline solar modules) provide 291 kWp of power.
- Produces 450 MWh of electricity per year.
- System installed and operational in under 16 weeks.
- Aesthetic design a crucial component.
- Rooftop or building integrated (BIPV).
- Cable routing and building interconnection.

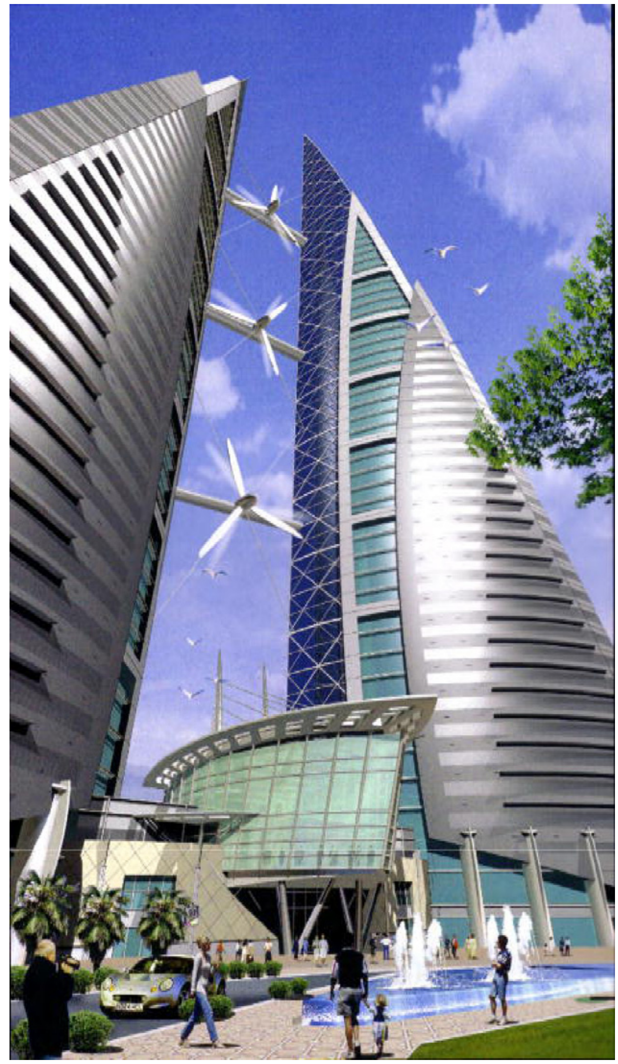


Fig. 27. Bahrain World Trade Centre (BWTC) with three parallel turbines total of 0.770 MW; a unique building at the international level.

Fig. 28. The Euro-University in Bahrain is a unique proposed project. It consists of much PV roofing to provide electricity for the lecture halls. The project was supposed to start in 2005 but it was delayed.

Fig. 29. Bapco First Zero Emission House (7 kW: solar, wind and fuel cell) – Dar Al Nakheel (the circle) – in Sheikha Sabeeka Bint Ebrahim Al Khlaifa's Park at Awali, Kingdom of Bahrain.

Fig. 30. Scientists and Engineers who will follow and promote renewable energy in Bahrain and worldwide after their interaction with Bapco's first Zero Emission House, Kingdom of Bahrain.

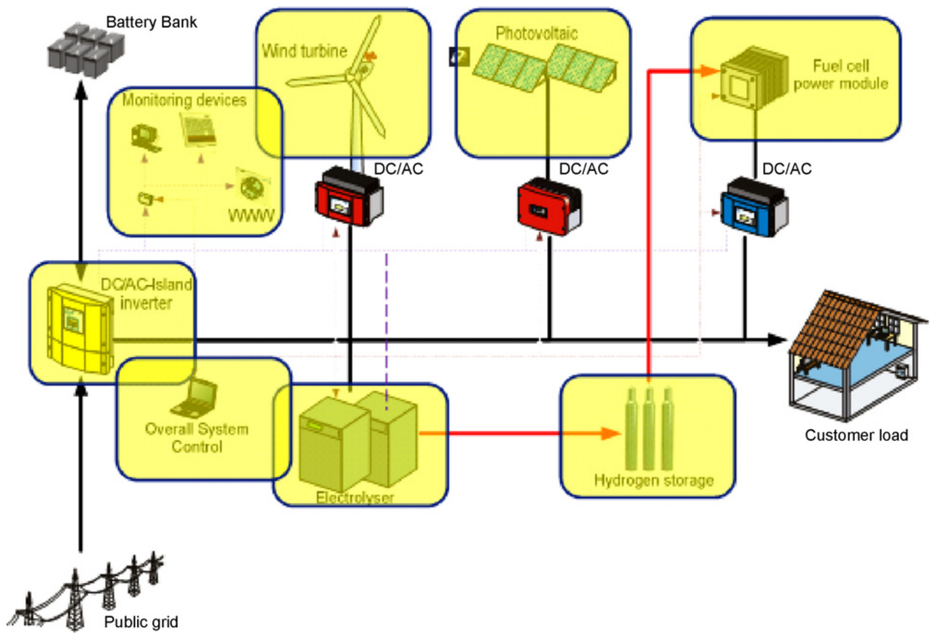


Fig. 31. Systematic diagram of the Bapco's Zero Emission House, Kingdom of Bahrain.

Output nominal AC voltage	230V / 50Hz
Output AC power 25°C / 45°C	4.200W / 3.400W (2.200/1.600W)
Input AC voltage (grid)	230V / 50Hz
Max. efficiency	95% (93%)
Battery voltage	48Vdc (24Vdc)
Battery charging current at 25°C	80A (80A)
Battery capacity	1000Ah

Fig. 32. The Characteristic of e Invertors of the Bapco's Zero Emission House, Kingdom of Bahrain.

It is worth mentioning, herein, that the 10 MW PV Masdar project and 291 kW PV Shams project had allowed investors and policy makers to evaluate the cost of kWh from PV electricity for either ground mount or roof top. The results are illustrated in Table 9. It is interesting to note that the cost of PV kWh is maximum of US ¢ 27 for ground mount and US ¢ 35 for roof mount. In Bahrain, each citizen is paying only US cent 1 for each kWh for consumption less than 3000 kWh while Qatari's pay nothings.

7. MW Solar Thermal Projects in Ras Al Khaima in UAE [30,31]. It is a circular Solar Islands with a diameter of 5 km and height of 20 m consisting steam storage, carrying the termosolar concentrator solar power (CSP) panels placed on a membrane (Fig. 21). The platform can be floated on high sea or land. The concept is made by CSEM, Switzerland (www.csem.ch). It is the first rotation test of the solar Islands prototype, constructed in the Emirate Ras Al Khaimah (RAK) in the UAE.

8. Solar power for water heating at Burj Khalifa. Burj Khalifa, is using solar power, since April 2010, to meet the bulk of its water heating requirements (Fig. 22). The tower, which is the tallest in the world (818 m), is using solar panels to heat 140,000 L of water every day, which will be distributed to homes and commercial entities within the tower. The solar powered water brings energy savings

Main Components – Solar Modules

» **Key Features:**

Maximum power	200W$_p$
Nominal voltage	24V
Short circuit current	8,5A
Voltage at maximal load	25Vdc
Current at maximal load	8A
Dimensions	990 x 1480mm
Mounting	Adjustable aluminum brackets
Pieces	10

Fig. 33. The Characteristic of the solar modules of the Bapco's Zero Emission House, Kingdom of Bahrain.

Rated power	1000W (12,5m/sec)
Cut in wind speed	2,5m/sec
Cut out wind speed	50m/sec
Output voltage	25Vdc
Rotor diameter	1,8m
Mast	~8m heights
Communication interface	RS485

Fig. 34. The Characteristic of the wind turbine of the Bapco's Zero Emission House, Kingdom of Bahrain.

Main Components – Hydrogen Generator

» Key Features:

H2 purity	6.0
Pressure	0,1...10,5bar
Max. H_2 flow rate	60Nl/h
Power consumption	450VA (full load)
Mains	230V / 50Hz
Communication	LCD Display + I/O-board
Cascading	Up to 10 units
Pieces	2
Maintenance	Only ion-filter/ extremely safe device

Fig. 35. The Characteristic of the reformer to separate water into hydrogen and oxygen using solar and wind electricity of the Bapco's Zero Emission House, Kingdom of Bahrain. The oxygen is pump to the house (fresh air).

Capacity	600NL @10bar
Max. refilling pressure	10...17bar
Dimension	90 x 425mm
Weight	7kg
Pieces	4
Refilling time 0..100% (suggested system sketch: 2xHG60 – 4 canister)	~ 1 day

Fig. 36. The Characteristic of the hydrogen storage cylinder or canisters at Bapco's Zero Emission House, Kingdom of Bahrain.

Rated power	1200W
DC voltage range	22...50V
Rated current	46A
Emission water	870ml/h @ rated power
Fuel consumption	18,5Nl/h @ rated power
Dimensions	56 x 25 x33mm

Fig. 37. The Characteristic of the fuel cells at Bapco's Zero Emission House, Kingdom of Bahrain.

equivalent to 3200 kW per day and 690 MWh of energy per annum [32].

This project is a perfect complement to the sustainable development initiatives spearheaded by the UAE. The solar heating system is installed and operated by SOLE UAE Solar Systems, the oldest solar thermal company in Europe. Burj Khalifa presented us a remarkable opportunity to use solar energy to meet the water heating needs of residents in the tower. The significant benefits include cost savings on energy uses – not only for the tower but the government utility provider too – as well as reduced pollution levels leading to a healthier environment. The solar panels serve as solar collectors, as against photovoltaic electricity generation technology. Located on roof of the offices, the annexure of Burj Khalifa 378 collector panels, each 2.7 m^2 in area (total solar collector area is 1021 m^2), can heat the entire 140,000 L of water in approximately 7 h of day time solar radiation.

Among other key sustainable energy and water use measures, the condensate from all the air-conditioning equipment in Burj Khalifa is reclaimed to cool the potable water from Dubai Electricity and Water Authority. The condensate is then collected in an on-site irrigation tank and used for tower's landscaping. When operational, this system will provide about 15 million gallons of supplemental water per year.

6.2. *Kingdom of Saudi Arabia*

Saudi Arabia has a bright history on the utility of renewable energy. They had made an extensive project in all renewable energy aspects in 1980s in collaboration with USA and Germany [33]. Table 10 summarizes the major projects that were made in Saudi Arabia [34].

Electricity consumption rates in Saudi Arabia have been steadily on the rise over the past three decades. While the population of about 26 million is growing at a high rate of 3%, the growth in total number of power utility customers is increasing at a higher rate of 5%. Between 2006 and 2007, the Saudi Electric Company, SEC reported an 11.9% growth in total peak loads, which reached 34,953 MW in 2007. Studies show that power demand in Saudi Arabia is expected to continue its rapid increase to reach 60,000 MW over the coming 15 years. In addition to the high rate of population growth, the expanding in industrialization and development plans is among the factors contributing to the rapid increase in power demand in Saudi Arabia [35]. The following developments exist in Saudi Arabia:

1. Recently, Saudi Arabia has embarked on a massive programme to build huge new power plants, many of them linked to water desalination. The cost is $111 billion to produce 2000 MW of new electricity generation each year for the next 10 years. Although natural gas will be the main fuel, however, nanotechnology and solar PV are also considered. Also, King Abdulla University of Science and Technology (KAUST) is focusing on clean energy and development in solar.

IBM in partnership with a team of researchers from the King Abdulaziz City for Science and Technology, conducting a pilot project to test two new technologies from IBM's research team: a nano-material membrane that will help to chemically separate water from salt and other elements found in ocean or brackish water, and a concentrated solar system with an innovative cooling mechanism that will allow it to take better advantage of the desert heat and fuel the desalination process with renewable energy [36,37] (Fig. 23).

The theoretical minimum amount of energy required to desalinate a 1 m^3 of water is nearly 10 kWh [38] were their system would is expected to be lower than this value, if not the same. At the IBM/KAST Saudi Arabia plant, a solar concentrator system will capture energy equivalent to 1500 suns, according to IBM, powering a plant that will produce 30,000 m^3 per day of fresh water for a city of 100,000 people.

There are currently more than 12,000 desalination plants in the world (nearly 18% are in Saudi Arabia), and as that number grows, it could have a drastic effect on marine ecosystems as the smallest organisms are routinely sucked into a pump and crushed against membranes. With multiple desalination plants already in place, Saudi Arabia's present oil consumption rate runs to approximately 1,500,000 barrels-a-day, but the cost linked to this can be cut significantly by drawing on solar power.

The solar desalination sites in Saudi Arabia will be created incrementally. To begin with, a small-scale plant with a daily water

State of the art device	PLC, PC or similar
	Central interface to all devices
	Customized controller software
	Automatic / manual mode
	Parameterization possible

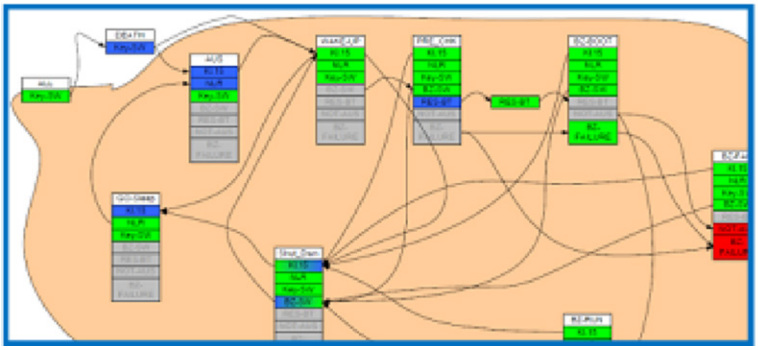


Fig. 38. The main component of the overall system control at Bapco's Zero Emission House, Kingdom of Bahrain.

output of 30,000 m^3 (about 850,000 m^3 less than the output from the fossil fuel-powered Shoaiba 3 – the largest desalination site on the planet) will be assembled. Next will be a plant capable of producing 100,000 m^3 on a daily basis – leading up to a whole fleet of sites geographically dispersed so they cover all of Saudi Arabia.

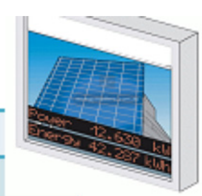
According to data issued by the World Bank, in 2005, Saudi Arabia produced 16.5 tons of CO_2 emissions per capita. This put it among the world's highest polluters in per capita terms, with Australia – by way of contrast – topping that year's leader board, producing over 25 tons of carbon dioxide for every person living there.

2. Saudi Arabia (SA) had created City for nuclear and renewable energy. This city is to meet the country's growing energy needs and reduce its dependence on fossil fuels. The King of SA issued a royal decree on 17 April 2010 ordering the creation of the King Abdullah City for Atomic and Renewable Energy (KACARE), based on Riyadh, with off shoots across the country.

KACARE aims to contribute to sustainable development by promoting renewable energy and the peaceful uses of atomic energy in areas such as agriculture, desalination, medicine and mining. Its work will support scientific research and development, training programmes and conferences, and co-ordination of the country's renewable energy centres. It will be responsible for drafting a national policy on nuclear energy development, and supervising all commercial uses of nuclear power and handling of radioactive waste.

The city is supervised by a 13-member council of representatives from relevant ministries. Internationally, KACARE will represent Saudi Arabia at organisations such as the International Atomic Energy Agency (IAEA).

» **Key Features:**



Custom large format display	Outdoor 80 x 100cm
	Up to 4 lines
	Time, Date, Personal Text, Personal Web Text, Current performance, daily yield, total yield, CO_2 saving, ambient temperature, module temperature, internal irradiation, wind speed, battery state of charge SOC
Internet interface	Promote your data online
Customized desktop on your computers	Customer interface Manually ON/OFF Monitors measuring data Start/Stop data capturing Shows device status

Fig. 39. The main component of the overall system control at Bapco's Zero Emission House, Kingdom of Bahrain.

Fig. 40. The monitoring system of the Bapco's Zero Emission House, Kingdom of Bahrain. There is indoor and outdoor display of energy yield from solar, wind and water energy in kWh with the equivalent of saved CO_2.

Saudi Arabia's renewable energy plans – like those of other member states of the Gulf Cooperation Council (Bahrain, Kuwait, Oman, Qatar and the United Arab Emirates) – focus on solar and nuclear energy. The council is currently preparing a regional nuclear power and desalination programme in cooperation with the IAEA.

3. Suadi Arabia had established Saudi Green Building Council and promotes the certification of LEED (Leadership in Energy Environmental Design, offered by US Green Building Council USGBC – a member of World Green Buildings Council, USA) to the Governmental Building. They had started with the newly established King Abdul Aziz University for Science and Technology (KAUST).

King Abdullah University of Science and Technology has been awarded the prestigious LEED Platinum certification from USBBC. The LEED Platinum certification is the highest of five possible environmental certification awards given out by the USGBC [39]. This is the first LEED certified project in Saudi history and is the largest LEED Platinum project in the world. UAE had two buildings with LEED Platinum but for private sector.

From inception, the campus was designed to be environmental friendly. The University will act as a living laboratory by demonstrating that environmentally responsible methods of energy use, materials management, and water consumption are viable in the Middle East and across the globe. KAUST has the following features:

Alternative transportation reduces campus emissions and provides convenient transit options

- Hundred shared electric vehicles and charging stations are distributed across campus, and additional vehicles will be added as the University grows in size.
- Three campus shuttle bus system lines with dedicated stops across campus serve the entire community.
- A Segway and bicycle sharing system provide additional short-distance travel options in most months of the year.

Renewable energy to cool and power the campus

- 4134 m^2 of solar thermal panels for hot water production and 16,567 m^2 of photovoltaic arrays installed on the monumental roof (producing 4 MW of renewable energy), off-setting 5.7% of total campus energy demand (Fig. 24).
- Two solar chimneys (or called wind towers) use the sun and prevailing winds to create a passive pressure difference and continuous breeze along the shaded courtyards and allow exterior courtyard occupants to feel comfortable for more than 75% of the year (Fig. 25) [39,40]. These wind towers induced natural ventilation during the day even in the absence of wind by absorbing solar heat, using a dark surface at the top of the tower. The hot dark surface heats the air around it which rises through an opening at the top of the tower, drawing cooler air from below to replace it.
- The air draw at the base of the tower creates air movement in the circulation spines connected to the tower. Computational fluid dynamic studies (CFDs) were carried out for the solar towers to optimize their design. The use of the solar chimneys, together with the prevailing Red Sea winds helped create a natural ventilation effect that provides a high level of comfort throughout the year for people using the circulation spine areas, saving the need to condition approximately 1 million ft^2.

The natural habitat surrounding KAUST has been preserved and protected

- A long-term habitat preservation, restoration and protection plan was implemented during construction and will continue through the University's existence for the 18,298,800 m^2 of coral reef and 2,152,800 m^2 of mangrove ecosystems on campus.

Campus architecture is designed to maximize the area's unique microclimate and ecosystem

- The University's monumental roof connects and shields campus buildings from direct sun, resulting in a minimum solar reflective index value of 78 for 92.7% of the roof's surface.
- Atria and courtyards throughout campus buildings infuse natural daylight and ventilation into 75% of interior spaces.

Campus construction and design teams selected building materials that minimized environmental effects and recycled waste materials

- 37.8% of the total building materials comprise materials and/or products either harvested or manufactured within 500 miles of the University, such as stone or concrete.
- 99.7% of all wood-based building materials used in construction were harvested from forests certified by the Forest Stewardship Council (FSC).
- 20% of the total building materials (such as steel, aluminum, and glass) were manufactured using recycled materials.
- More than 79%, or 35,169 tons, of all construction waste generated on site was recycled and diverted from landfill.

Water and material use has been minimized through innovative design and on-site treatment plants and recycling programs

- 100% of KAUST's wastewater is treated by the campus Waste Water Treatment Plant (WWTP). All treated wastewater is either safely returned to the environment or used on site. 100% of all campus irrigation needs are provided by the WWTP, and 2.5 million gallons of treated water per day will be available in 2010.
- Installed irrigation systems using recycled water reduce irrigation water consumption by 53.8% of estimated need.
- Waterless urinals, ultra-low flow lavatories, and low-flow public showers reduce potable water use by 40.9% from a calculated baseline design.
- Native and adaptive vegetation were which do not require large amounts of irrigation were selected for a majority of the plantings on campus.
- A storm water management plan reduces impervious cover, promotes groundwater infiltration, and will capture and treat 100% of average annual rainfall runoff.
- A campus-wide recycling program will recycle cardboard, paper, plastic, glass and metal.

Energy efficiency measures reduce total power demand

- Technology like chilled beams and under-floor air distribution have been incorporated into designs to achieve energy cost savings of 24.5%.
- Highly efficient mechanical, electrical and plumbing systems reduce the overall energy demand of the campus.
- Non-emergency occupancy sensors automatically turn off lighting systems when a room is unoccupied and astronomic time-clock systems calculate sunrise/sunset times each day to automatically dim interior lights.

4. Establishment of development, manufacture and operation of solar power plants to generate electricity. Vision Electro Mechanical Co (Vision), a subsidiary of Construction Products Holding Company (CPC), has formed a company with a capital of $150 million for the development, manufacture and operation of solar power plants to generate electricity in SA. The company started the building of a solar field at its industrial complex in Bahra, Makkah region. The solar power field is designed to cope with the atmosphere of the GCC region, and will keep track of the Sun's movement throughout the day to maximise the potential use of solar energy. However, this project will not only serve to SA only but the needs of power projects throughout the Arabian Gulf region [41]. This project will contribute in preservation of conventional sources of energy, primarily oil, for future generations.

6.3. State of Qatar

Qatar had entered the era of renewable energy as early in the 1990s when University of Qatar had made a solar pond for the purpose of water desalination [42]. The purpose of that work in 1992 was to use a solar pond to provide air conditioning for a typical small family Qatari house where it was found that to meet 100% of the cooling load from March till December; the solar pond area needed is 4–5 times the floor area of the air-conditioned space.

Now, Qatar is opting for huge investment and utility of renewable energy. Among these dreams is what is broadcasted in the TV space channels on making many football stadium cooled using Green Sources and Technology like solar power in order to host the world cup in 2022 in Doha. Furthermore, there are several projects in renewable energy but the hero is now Qatar Foundation for Education, Science and Community Development. The country is boosting in real estate construction and to further develop the infrastructure.

Qatar Electricity & Water Company (QEWC) has the capacity to provide sufficient power supply till 2015 with the help of its new plants and to meet the increasing demand for water it will build a new water plant in 2013. The first phase of the multi-billion dollar Ras Girtas power and water plant in Ras Laffan Industrial City in Qatar has been complete. The initial phase has the capacity to generate 1833 MW of power and once fully operational, the project will have a total capacity of 2730 MW. Upon completion of the first phase, a total of eight gas turbines have become operational. The desalination units will start functioning from October 2010. The plant would be fully operational in April 2011. The plant, the latest and largest in Qatar, will be capable of providing 63 million gallons per day of potable water once the project becomes fully operational. It will also provide Qatar a total power generating capacity of 9039 MW and a desalination capacity of more than 320 million gallons per day. The development of huge power generation and desalination capacity is being undertaken to ensure there is sufficient power and water to meet an expected growth in demand and also for the possibility of exchanging the commodities with other GCC countries. The followings were the major planned projects:

1. Qatar plans US$ 1 billion solar power plant project. This was announced on 07 January 2010 [43,44]. Around 25 local and international investors have emerged as potential partners for the project. This major solar energy plant is with an aim to generate at least 100 MW of solar power within five years. Over US$ 500 million will be invested by Qatar Foundation in a plant to make polycrystalline silicon, the much sought-after raw material for solar cells. The project will take two years and the hi-tech, modular plant is to be built in Europe by a leading manufacturer and put together in Qatar on site, Qatar Science & Technology Park (QSTP). This solar facility is expected to produce 3000 tons a year, and might go up to 12,000 tons later. QSTP will also encourage its tenants Tata, Chevron, Shell, and Total, which are major players in solar, to collaborate with the country's companies emerging in the sector. QSTP will have a majority shareholding in Qatar Solar Technologies, or QST, a joint venture with SolarWorld AG, one of the world's largest solar companies, which is headquartered in Bonn, Germany. Qatar Foundation's ownership stake will be 70%, and that of SolarWorld 29%, with an additional 1% in the hands of the Qatar Development Bank [45].

QST will develop a new plant at Ras Laffan Industrial City, in the north east of Qatar, which will be one of the first operational polycrystalline silicon plants in the region. The plant will produce well over 3500 tons per annum and has been designed with future expansion in mind which would enable it to significantly increase production capacity. The process technology and equipment to produce polycrystalline silicon will come from the leading German solar company Centrotherm Photovoltaics AG. Economists foresee that new solar-grade polycrystalline silicon production capacity eventually will cut the price, now averaging $100/kg in world markets, to US$ 25.

2. Qatar has won the bid to World Cup 2022 on 2nd December 2010, which includes a slew of solar powered stadiums as well as significant upgrades to their public transportation network. Qatar

will build three brand new Green Stadiums and update two existing ones in order to host the games [46] using solar technology to power carbon-neutral technology in order to cool the stadiums and keep the temperature inside less than 27 °C (Fig. 26).

Albert Speer & Partner GmbH, in cooperation with ProProjekt, have put together the bid book on behalf of Qatar. Three new eco stadiums and sports complexes will be built close within the city limits allowing fans as well as teams to easily access the arenas. Stadiums will be able to host over 45,000 spectators.

3. Plans by Chevron in Qatar to test solar panels and energy-efficient lighting in Qatar will soon be put into action [47]. The company is investing $20 m over five years in its Centre for Sustainable Energy Efficiency at Qatar Science & Technology Park (QSTP). Chevron is working with local organisations to identify and deploy sustainable energy technologies specifically suited to Middle East conditions. This is a needed collaborative partnership in this region which spur the adoption of Green Technologies.

The Centre for Sustainable Energy Efficiency is expected to open in October 2010 and aims to identify solar power, solar air conditioning and low-energy lighting technologies best suited for Qatar's climate. Chevron is making use of Qatar's excellent education and research base, plus abundant sunshine, provides the opportunity to introduce green technologies for the benefit GCC region.

6.4. State of Kuwait

Kuwait, has one of the world's highest per capita power consumption rates, and has said it plans to boost power capacity to around 16,000 MW from 10,000 MW by 2012. Kuwait experienced power cuts, especially during the hot summer months when air conditioning use rises.

Kuwait has six power stations that also desalinate water, has signed a $2.65 billion deal last month with General Electric Co. and Hyundai Heavy Industries to build and operate the 2000 MW Subbiya power plant in the north of the country. The country is considering developing nuclear power with the help of a French firm to meet demand for electricity and water desalination.

Kuwait was leading the GCC countries in 1980s were through Kuwait Institute for Scientific Research (KISR) – which was employing and cooperating with leading scientists – has made several pilot projects in Wind, PV and Solar thermal technology. More than 140 research projects were conducted, totaling around $50 million, involving more than 70 researchers, engineers and technicians [31]. Among these projects were Solar Heating and Cooling with different Thermal Storage configurations; Water Desalination and Greenhouse Food Production; Solar Cooling project-known as MOD Office Building – with 172 solar collectors covering total area 300 m^2; Solar Thermal application projects including Sager Al-Rashood Kindergarten with 90 solar collector covering total area 300 m^2; Thermal and Electricity application projects including Kuwait English School (Salwa) with daily electricity load of 80 kWh, 630 PV modules and 110 batteries with electricity production capacity of 24.2 kW; KISR's Solar House (application laboratory) with 76 PV modules, 48 batteries and electricity production capacity of 2.6 kW; Solar Power plant at Sulaibia complex with 56 parabolic trough dishes with Storage Thermal unit of 50 kWh and Power production of 125 kW. Recently, the following renewable energy projects have been announced:

1. Kuwait set to issue tender for solar power plant. The call for a tender is expected late this year (2010) for a solar energy plant, and aims for 5% of total supply from renewable energy by 2020 [48]. Solar energy in Kuwait is promising and various projects will benefit from it.
2. 15 MW PV and 10 MW Wind electricity. A joint project has been proposed between KISR and Germany to generate electricity form wind power with 15 MW capacities [49] and further project is in the pipeline for a solar-powered electricity station with a five to 10 MW capacity.
3. KUWAIT is also working now with a well-known Japanese company in order to prepare an economic study about establishing solar power stations. The study will also look into establishing water desalination plants which will be powered by solar energy. The country is looking for preserving Kuwait's natural resources and increase Kuwait's economy by concentrating on alternative energy sources [49].

6.5. Sultanate of Oman

1. According to the study made to the Authority for Electricity Regulation at Oman entitled "Study on Renewable Energy Resources", Oman – made by COWI and Partners LLC in May 2008 – several recommended pilot projects were made [50]. The criteria for selection of the recommended type pilot projects include:

- Demand for the type of project is expected in the future.
- The type of project is expected to be economically viable in the future assuming high conventional fuel prices in the future.
- The project shall contribute to the awareness of renewable energy in Oman.
- The project shall be based on well proven and reliable technology.

2. Solar pilot projects

Two types of solar energy systems were recommended as pilot projects in the report. One is a 20 kW system for installation on a building in an urban environment and the other is a 10 kW solar PV/diesel hybrid system. The total cost of these two projects was estimated as USD 150,000 [50].

3. Wind Power Project

It is recommended to implement a small pilot wind farm project in order to give demonstration the performance of the modern wind turbine technology under Omani conditions and to evaluate the interaction between the turbines and the grid. The wind farm should consist of five 2 MW wind turbines with hub height of approximately 80 m and rotor diameter of 90 m. The wind farm should be connected to the high voltage grid system in Dhofar. The total power capacity of the Salalah system is 350 MW. The 10 MW wind farm capacity will be 3% of the total power capacity in the Salalah power system. Based on the present market price the cost per MW installed capacity for on shore wind farms is in the order of 2 million USD. For the proposed pilot project the total construction cost will be USD 20–22 million.

4. *Calculation of Generation based on renewable energy*

The production cost of electricity based on the solar and wind energy resources in Oman has been calculated for four specific types of plant [50]:

- 20 kW grid connected solar PV plant.
- 20 MW grid connected solar PV plant.
- 20 MW grid connected solar thermal plant.
- 10 kW off grid PV-diesel plant.
- 20 MW grid connected wind farm.

4.1. Small grid connected solar PV plant, 20 kW

This application is foreseen to be implemented in an urban environment and comprises 200 m^2 conventional panels. It is an end-user application and replaces electricity from the grid at the customer level. In terms of comparison of cost it should therefore be compared with the end-user tariff (permitted Tariff). The result of the cost calculation is shown below:

Capacity: 20 kW
Capital cost: US$ 0.15 million
O&M cost: US$ 0.001 million per year
Power production (useful): 34 MWh
Lifetime: 25 years
Discount factor: 7.5%
Short run marginal cost: 0
Long run marginal cost: US$ 425/MWh

The long run marginal costs are estimated to US$ 425/MWh.

4.2 Large grid connected solar PV plant, 20 MW

This application is in principle identical to the previous, except for the capacity scale. The panels will cover an area of about 200,000 m^2 and be among the largest in world. The application will supply the grid and is the result of the cost calculation is shown below:

Capacity: 20 MW
Capital cost: US$ 89 million
O&M cost: US$ 0.5 million per year
Power production (useful): 36 GWh/year
Lifetime: 25 years
Discount factor: 7.5%
Short run marginal cost: 0
Long run marginal cost: US$ 250/MWh

The long run marginal costs are estimated to US$ 250/MWh for this application.

4.3 Solar thermal plant, 20 MW

The economic calculation for the solar thermal plant is valid for a plant without storage and with local estimated data. There are a number of plants under construction which includes storage of up 15 h capacity. This solar TRES plant is planned to generate 96 GWh of electricity per year with an investment cost not much higher than in the example below:

Capacity: 20 MW
Collector area: 130,000 m^2
Capital cost: US$ 72.5 million (US$ 3.6/W, includes connection cost to transmission system)
O&M cost: US$ 0.8 million per year
Solar insolation: 2200 kWh/m^2
Power production (useful): 35 GWh/year
Lifetime: 25 years
Discount factor: 7.5%
Long run marginal cost: US$ 207/MWh

The economic result depends on the lifetime of the plant, which is estimated to 25 year. Assuming a lifetime of 40 years, and a discount rate of 4% the economic cost of Solar Thermal Plane is US$ 126/MWh.

4.4 Small off-grid solar PV – diesel system, 10 kW

The system is configured with one10 kW diesel engine, 2 kW PV and 50 batteries with a storage capacity of about 25 kWh. The key figures in the cost calculation are shown below:

Capacity: 10 kW
Capital cost: US$ 32,800
Capital replacement cost: US$ 1900 per year lifetime varies per item
O&M cost: US$ 4600 per year
Power production (useful): 78 MWh per year
Lifetime: 15–25 years varies by item in the system
Diesel price: 146 Baiza per litre
Discount factor: 7.5%
Short run marginal cost: US$ 127/MWh
Long run marginal cost: US$ 245/MWh

The long run marginal costs are estimated to US$ 245/MWh. Approximately 5% of the electricity produced by the system will be solar.

4.5 Grid connected 20 MW wind farm

Table 11 list the assumptions regarding the construction costs for a 20 MW wind farm in Oman. It has been assumed that the construction costs are independent of the wind farm site.

The lifetime is assumed to be 20 years and the O&M cost 0.5 Mill USD per year. Like for the other plants the used discount rate is 7.5% p.a.

5. The Authority for Electricity Regulation in Oman has issued a landmark study which effectively charts a road map for the development of renewable energy resources in the Sultanate. In particular, the study underlines the strong potential for developing the country's limitless access to solar energy through the establishment of large-scale solar thermal plants. The study also identifies the long term potential for a wind farm of up to 750 MW in the south of the country following interconnection of the northern grid and the Salalah power system [51].

The study identifies the need for a Designated National Authority (DNA) in Oman to administer clean development mechanisms (CDMs) to assist renewable energy investment (as spelt out by the United Nations Framework Convention on Climate Change). Unfortunately, DNA has been formed very late in GCC countries where other countries had formed it since 2002.

6.6. Kingdom of Bahrain

According to the Minster of Works [52], the Kingdom of Bahrain pays a special attention to energy issues in general and the topics of renewable and clean energy in particular. The concerned authorities in the Kingdom are continuously searching for new energy alternatives that suit the local environment. Solar and wind energies always come as potential alternatives for two main goals, the production of electricity and reducing the pollution emitted from power plants operating with natural gas and diesel fuel.

Bahrain produces 2800 MW of electricity and 140 million gallons per day of desalinated water from the power stations and water desalination that employ fossil fuel as the main energy source from the government and private owned installations that consume nearly approximately 583 million ft^3. With an estimated annual energy growth rate of 10% which is a very high rate, the required amount of natural gas will be doubled in less than a decade. This requires serious consideration in finding potential alternative sources of energy including renewable energy.

The economic potential within an annual average daily solar radiation measures of 5.2 kWh/m^2 (reaching maximum values of 6–7.2 kWh/m^2) during summer season) is considered very appropriate to make the cost of solar energy in the medium term competitive with conventional sources of energy and other renewable power resources. Thus, the Kingdom of Bahrain and the rest of the Gulf Cooperation Council states which falling within the solar belt are very qualified to take advantage of these technologies.

Though the survey study for Bahrain showed low to moderate wind speeds throughout the year, averaging at 5 m per second, it is possible to harness this energy for the production of electricity around the coastal areas with higher wind speeds due to its advantages. The Bahrain World Trade centre will be the first of its kind to utilize wind power to support upto15% of building needs for electric power and will be fully operational by early 2009.

In previous paper [31] we had highlighted on several renewable energy projects in Bahrain including the Bahrain world trade centre, which contains three parallel 29 m in diameter wind turbine – at

different height and integrated to the building – offering nearly 770 kW of electricity (Fig. 27) as well as Euro-University; a project that was officially inaugurated by high official from Bahrain and Germany but not started yet. This project should be the first Low Carbon Building Integrated Photovoltaic (BIVP) in the Middle East (Fig. 28).

A detailed work on Renewable Energy utility in Bahrain, in general, and for buildings, specifically, along with all policies, economic and environmental impact is made very recently by Alnaser [53]. However, the latest renewable energy projects, both conducted and planned, are the followings:

1. Bapco's (Bahrain Petroleum Company) First Zero Emission House (nearly 7 kW solar, wind and fuel cell)

   This project was part of a grand project to Green Bahrain. It is a Dar (Dar means house in English) in Sheikha Sabeeka Bint Ebrahim Al Khlaifa's Park at Awali, Kingdom of Bahrain (Fig. 29). The project costs, nearly, €100,000. It was the author's initiative which was accepted and conducted by Bapco. Heliocentric Energiesysteme GmbH, a Berlin based company, Germany, had provided the technical advice.

   The park was installed in the park in February 2010 and was officially opened in March 2010. It is the first Zero Emission House in the Middle East. This house is in fact an International laboratory for conducting and evaluating renewable energy for building. This is because any student in the world can log in the web site of the company and later to the house site to read all solar and wind data and how much energy is obtained in kWh (and the equivalent CO_2 saving) is obtained bearing in mind the prevailing dust, humidity and aerosols. The house consists of 4 kW photovoltaic, 1.5 wind turbine and 1.2 kW fuel cell (water energy) – total of 6.7 kW. Special reformer was made to separate water to hydrogen and oxygen using solar and wind energy; where the hydrogen and air were used as input for the fuel cells to produce electricity – with water as waste. Lab is being developed in line with Bapco's objectives to conserve energy and increase public awareness on the use of renewable energy.

   Bapco had made an excellent administration in forming a team consisting members from University of Bahrain, Electricity and Water Authority, Ministry of Housing, Ministry of Work and Ministry of Municipality and Agriculture and National Oil and Gas Authority (NOGA) (Fig. 30). This team is to follow up the project and promote Renewable Energy technology in Bahrain and worldwide. Figs. 31–40 display the main features of each component of the Renewable Energy system in Bapco's First Zero Emission House in the Kingdom of Bahrain.

2. A 5 MW solar and Wind power plant

   The Electricity and Water Authority Electricity and Water Authority Electricity and Water Authority in Bahrain had already put bidding for 5 MW solar and wind power plant. 50% of this plant will be solar (PV technology) and 50% is wind technology [54]. The project will help in reducing the environmental damage. The measured wind speed in Bahrain at 50 m height was found to be nearly 6 m/s. This means that at 100 m height it may reach an average of more 7 m/s – which is economically viable. This plant will contribute to 2% of the primary electrical energy produce in Bahrain in 2012 which is planned to grow to 15% in 2030 where the total electrical power will reach 5700 MW.

   In September 2010, the project consultant is expected to be appointed (delayed from December 2009). The project was announced in September 2009. EWAEWA will finance the project.

3. A $200 m solar panel factory

   A solar panel factory will be built in Bahrain at a cost of BD 75.6 million (US$ 200 million). The new plant is expected to be ready by the end of next year and will create around 200 jobs. The investor is Nasser S Al Hajri Corporation [55]. The solar panels would be exported to Europe for domestic and industrial use. The company has invested in this venture because of its belief that the future is in alternative sources of energy. Solar power and other alternative means are rapidly gaining ground all over the world and five years from now. The company is hoping that there would be a market for solar panels in Bahrain. They are looking at a long-term plan to market these panels in Bahrain and the other GCC countries. The initial focus will be on Western markets and the factory is being built in co-operation with a Dutch company.

7. Conclusion

Electricity consumption in GCC countries is only 0.5% of the world (0.5% of world population), 9.8% of EU (7.8% of their population), 8.8% of China (2.7% of their population) and 7.4% of USA (12% of their population) in 2009. The rate of increase in electricity consumption in GCC countries from 2005 to 2009 was 8.87% (largest rate was in Oman, 22.6%, and least in SA, 6.3%) with average per person of 1149 W – which is 3.9 times the world average, 0.8 of USA average, 4.2 of China average and 1.7 of EU average in 2009.

The GCC countries are the main investors in renewable energy in the Middle East. It is expected that new solar and wind generated electricity in the GCC is expected to reach 10 GW by 2022.

According to the World Energy Council (WEC) the total current CO_2 emission to planet earth made by the GCC countries is not more than 2.25%; 0.1% for Bahrain, 0.4% for UAE, 0.1% for Oman, 1.2% Saudi Arabia, 0.2% for Qatar, and 0.2 for Kuwait. WEC, estimated that the GCC countries will require 100 GW of additional power over the next 10 years to meet its ever growing demand.

Using renewable energy in the GCC countries will help in prolonging the fossil fuel and reduce the carbon foot print in the region – which in average 20 tonne per capita with highest in UAE (nearly 60 tonne per capita) to lowest in Saudi Arabia (nearly 18 ton per Capita). This will also has an impact in worldwide use petroleum which is now 80 million barrels – of this, 53 million goes for general transport, 5 million for travel and air transport, 19 million for land transportation and 29 million for land transportation [56].

By 2015, Renewable Energy utilization in the GCC countries may be reach 13,000 MW distributed as follows: Saudi Arabia 4000 MW, UAE 2000 MW, Bahrain 1000 MW, Qatar 3500 MW, Oman 1000 MW and Kuwait 1500 MW. This makes the expected investment in 2012 in GCC counties is US$ 150 billion. This will make Green collar jobs in the region with reformation in higher education.

Based on the expansion of the GCC countries in 2010 in electricity-generating capacity it is expected that they are expected to invest US$ 200 billion to US$ 250 billion in between 14 and 20 energy projects by 2020.

The GCC countries need an area of 350 km^2 from the land of GCC countries, to install CSP (efficiency of 50% and solar radiation of 500 W/m^2 and 9 daily average sunshine hours), to produce annually 287,342 GWh – which is equal to total electricity consumed in 2009 in GCC countries. This would cost US$ 90 billion. For PV the cost will be no more than US$ 150.

The GCC countries can install 11,000 wind turbines; each rated 5 MW, will to provide 287 TWh annually equal to the electricity consumed in the GCC countries in 2009. This is assuming that the wind turbines will operate 60% of time per year at full capacity. 5 rows will be needed along the GCC coast (2221 km long) and 5 km deep in the sea. This would cost no more than US$ 50 billion.

Finally, it is expected that by 2015 all GCC countries will have a PV manufacturing plant (thin film and crystalline silicon). This will, hopefully, will fulfil their need for solar energy projects and will put them in the world solar market.

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